Investigation on the Relationship between Fracture dimensions and Proppant Selection for Shale Gas Reservoir

By

HAMDY FATHY MOHAMED

14703

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Petroleum)

January 2015

Universiti Teknologi PETRONAS

32610 Bandar Seri Iskandar,

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MALAYSIA

CERTIFICATION OF APPROVAL

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Approved by,

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(Ms Nur Asyraf Md Akhir)

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Hamdy Fathy Mohamed

ABSTRACT

The Search for new sources of energy has always been motivated by both economical and political reasons. This made the oil and gas industry look into resources that was overlooked before. Shale gas reservoirs represent a huge potential for gas reserves. However, the production process from shale gas is very complex due to the low permeability and the dual porosity nature of shale formation. Many parameters affect the process which in turn make the optimization of these parameters a very complex process.

This project aims to create a matlab program to solve for a model of equations to arrive at the optimal parameters for the fracturing stimulation. This program uses the unified fracture design model to calculate the optimum fracture width and length for maximum fracture conductivity. In this project, the fracturing process of the reservoir is analyzed while explaining the role of the proppant agent selection and the fracture width for an optimal productivity after the process. The selection of the proppant is also discussed to arrive to the best proppant selection based on the type, size and concentration of the proppant.

After creating the model, a sensitivity analysis of the fracture parameter is conducted to determine the inter-relationship between these parameters. And how these parameters affect each other and affect the process of hydraulic fracture. The relationship between the proppant volume and fracture half-length and maximum dimensionless productivity index is analyzed showing the effect of increasing the proppant volume on both of these parameters.

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NOMENCLATURE

N_{prop}	proppant number
K_f	fracture permeability
K	formation permeability
V_p	proppant volume
X_f	fracture half length
W_f	fracture width
C_{fD}	dimensionless facture conductivity
J	productivity index
y_{eD}	dimensionless fracture ratio
σ	formation stress
ϵ	formation strain
E	Young modulus
ν	Poisson ratio

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Natural gas exists in natural reservoirs in four main forms either the conventional gas reservoirs or conventional associated gas with oil reservoirs. On the other hand natural gas can also exist in gas-rich shale reservoirs and coalbed methane. (Figure 1.1) shows the different categories of gas reservoirs.

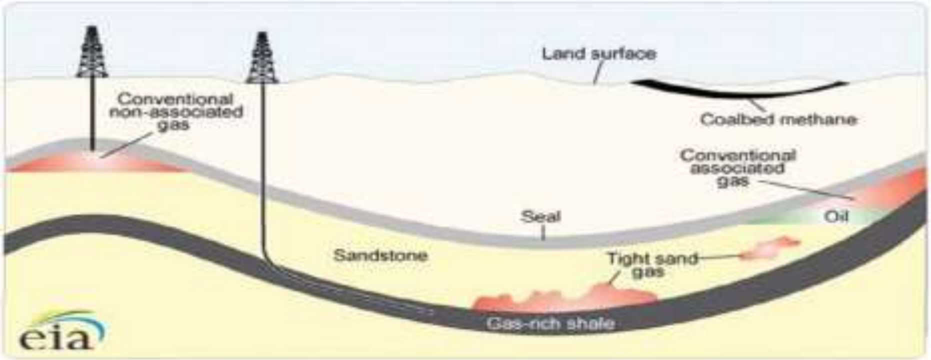


Figure 1.1: Different types of gas reservoirs (Donaldson, Alam & Begum 2013)

Shale gas reservoirs has become one of the concentration point of the major oil and gas companies. As the whole industry is focusing on new technologies for production from non-conventional reservoirs. As the existence of easy-producing, conventional reservoirs has become more and more challenging. Currently most of the gas production comes from conventional reservoirs. However, the production from shale gas reservoir is increasing rapidly and it is effectively replacing production from conventional reservoirs. NETL (2011) predicted that, by the year 2035, 45% of the American production of dry gas will be from shale gas reservoirs. The increase in production of shale gas is shown in the Figure 1.2.

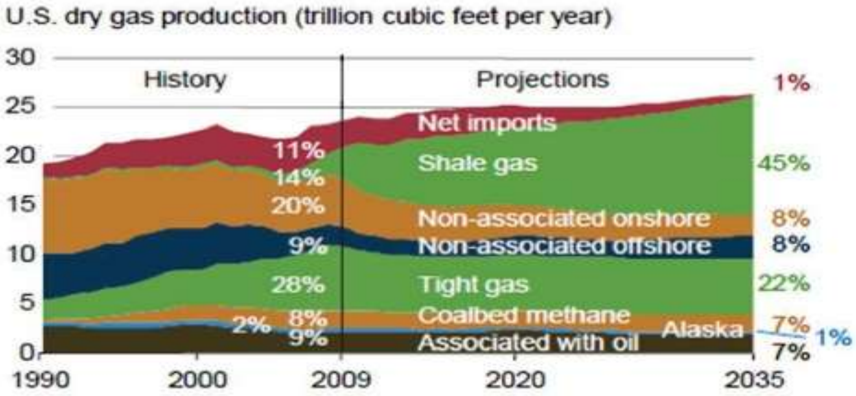


Figure 1.2: Dry gas production prediction USA by (NETL, 2011)

Shale reservoir is conceptually different than conventional reservoir due to the dual porosity nature of the shale reservoir as shale reservoir are generally naturally fractured reservoir therefore it is represented by two sets of properties; the properties of the matrix and the properties of the fractures. Another fundamental difference is the very low permeability stretching to just hundreds of nano-darcy making flow impossible without the use of external stimulation technique.

Shale gas reservoirs is containing a respectful amount of the gas reserves making shale reservoir hold a huge potential for producing hydrocarbon. However, the vast majority of these reserves could not be produced with conventional production techniques. Which motivated the oil and gas industry to find ways and new technologies to produce from these fields. Hence the introduction of hydraulic fracturing and horizontal drilling.

Hydraulic fracture can drastically increase the permeability of the formation by creating a highly conductive fractures that extent from the wellbore to several hundred feet into the reservoir. The basic idea of hydraulic fractures is a fluid alongside a proppant is pumped into the reservoir with a huge pressure that exceed the fracture pressure of the formation creating a network of fractures and the proppant to ensure that these fractures remains open.

There are number of factors that can affect the fracturing technique. One of which is the proppant selection. As any wrong selection of the proppant may produce sub-optimal stimulation. Another factor that affect the process is the fracture width, as for each formation there is a fracture width that corresponds to maximum fracture conductivity.

1.2 Problem Statement

In this project, the problem is how the wrong selection of the fracture parameters such as the wrong selection of proppant or fracture width can lead to sub-optimal fracturing operation.

The lack of harmony between selecting the proppant size and fracture width may cause a number of problem such as bridging when the proppant size is larger than the fracture width which may block some of the fracture network reducing its conductivity.

Another problem is the complexity of the equations used for determining the optimal condition for reservoir fracking also the knowledge of the industry about shale gas is still growing.

1.3 Objectives

1. To create a mathematical model of equations using matlab for the optimization of fracture parameters for optimum fracture stimulation
2. To examine the optimum proppant size in relation to fracture width.
3. To optimize hydraulic fracture parameter and measure its sensitivity to other variables

1.4 Scope of Study

In this project, the various parameters for a hydraulic fracture will be studied to create a model to help reservoir and production engineers to arrive at the optimal parameter for the reservoir stimulation fracture technique.

For proppant selection, the formation stress will be studied in order to choose the proppant type and the optimum fracture width will be analyzed to select the proppant size. The rock mechanical properties such as young modules will be studied to determine the viscosity of the fracking fluid and pump rate to achieve the wanted fracture design.

This project does not include the optimization for the cost of the treatment. However, the cost is always considered whenever the chance permits without compromising the optimization process.

This model will attempt to include a number of variables database so that it can be applied into different fields with different characteristics. Besides the model will be flexible to include new variables.

CHAPTER 2
LITERATURE REVIEW

2.1 Shale Gas

Shale is a fine grained sedimentary rock that deposits in low energy environment. Shale formation is not similar to most of the other geological formation as shale has a very low permeability which prevent the movement of fluids. Moreover shale formations are typically brittle which induce the existence of natural fractures (Speight, 2013).

Ideally, each hydrocarbon production system consists of three main groups. First, the source rocks which are very rich of organic matters and has the right pressure and temperature condition to allow these matter to cook into oil and gas. Secondly the reservoir rock which normally has a high porosity and permeability to allow the accumulation of hydrocarbon inside. Then there is the trap which are impermeably formations that ensure the trapping of hydrocarbon under (Speight, 2013).

Shale gas reservoir is fundamentally different than conventional hydrocarbon production system as shale formation works as the source rock, the reservoir and the trap. As during the deposition of shale organic matter such as plant debris and algae are deposited inside the shale. Providing the right pressure and temperature these organic matter turn into Kerogen which then turn to oil and gas. But due to the very low permeability, this oil and gas cannot leave the shale so it become trapped inside the shale formation (Wu & fakcharoenphol, 2011; Wei & Economides, 2005).

Shale gas refers to natural gas that is trapped within shale formations. Shale can be rich resources of natural gas. The potential of carrying inside a respectful amount of hydrocarbon made shale gas a concentration point of the whole industry (Romero, Valkó & Economides, 2002).

Wang and Krupnick (2013) debate that shale gas has become the best source for unconventional gas due to its large reserves besides the advances in production technologies that make the economic production from shale gas possible and it is just a matter of time when shale gas will effectively replace conventional gas.

Over the past decade, the combination of horizontal drilling and hydraulic fracturing has allowed access to large volumes of shale gas that were previously uneconomical to produce (Bhattacharya, Nikolaou & Economides, 2012).

2.2 Hydraulic Fracturing

Hydraulic fracture is a well stimulation technique that is used to increase the permeability of the formation and increase the productivity by inducing small fracture or cracks in the formation around the wellbore. These fracture may extend to several hundred feet into the formation (Donaldson, Alam & Begum 2013).

Hydraulic fractures use heavy machinery at the well site such as pumps, blenders and proppant tanks. The basic idea is that when a fluid is pumped into the formation with a rate higher than the rate that the fluid can escape to the formation, the pressure increases till it become higher than the fracture pressure of the formation which induce the fracture (Jones & Britt, 2009). The hydraulic fracture operation has encountered great growth in the technology and operation due to the need for hydraulic fracture for shale gas reservoir. Besides the advance of horizontal drilling and micro seismic survey has allowed better fracturing operation (Donaldson, et al ,2013).

The typical bottom hole pressure behavior vs. pumping time is shown in (figure 2.1). The pressure initially increase as the pumping time increase till it reaches the breakdown pressure which is the pressure at which the formation starts to break and the fracture starts to form. As the fracture form it provide a way for the injection fluid to escape into the formation which yield a slight decrease in the bottomhole pressure. Then the pressure reaches the fracture propagation pressure which is the pressure that is required to continue the enlargement of the fracture.

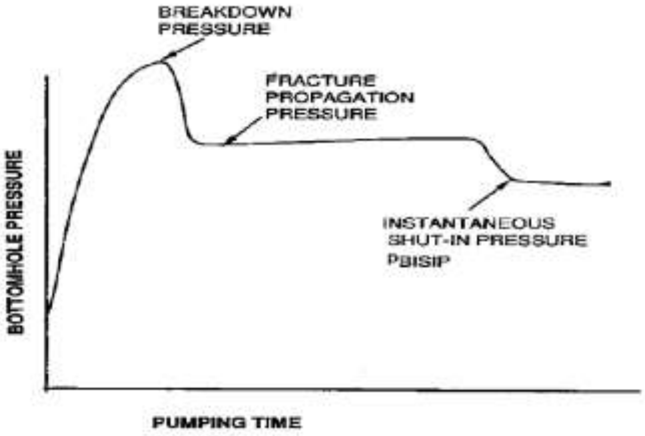


Figure 2.1: The Bottomhole Pressure vs Pumping time for Hydraulic Fracturing (Economides, Hill & Ehlig, 1994)

Every fracture that is made in beneath the surface of the earth is unique. Hydraulic fracturing aims to create and maintain a network of fractures to increase the productivity and ultimate recovery. It is produced by pumping fracking fluids and a proppant agent into the formation in high pumping rates which cause tensile failure of the formation rock at pressure exceeding the formation fracture pressure (Yang & Economides, 2012).

Fracturing has a long history in the industry. The first fractured well was in the year 1949 in the Hugoton gas field. This stimulation fracture only used gelled oil and gasoline without any proppant. It did not improve the permeability of the field as the fracture closed after the treatment due to the overburden stress which proved that the existence of proppant is crucial to keep the fracture (Britt, 2012).

Hydraulic fracturing is a multi-disciplinary operation that has a lot of factors, failure in optimizing any of this factors may lead to a sub-optimal well performance hence, less revenue from the well. It is important to discipline the reservoir engineering, the rock mechanics, fluid mechanics and stimulation design. As reservoir engineering indicate the areas with rich gas to be the target of the wells for production. The rock mechanics are important to understand the in-situ stress and the direction at which the fracture will propagate. Fluid mechanics shows the ability of the fracking fluid to produce the fracture and its ability to transport the proppant (Marongiu, Economides, & Holditch, 2008; Valkó, Doublet & Blasingame, 2000).

2.3 Rock Mechanical Properties

Any deep formation witnesses a number of stresses and forces acting on the rock due to the overburden weight of the rock and fluids besides the tectonic activities of the formation (Economides, Hill & Ehlig, 1994).

2.3.1 The Rock's Young Modulus

The rock's young modulus E is a representation of how the rock reacts to the applied stress. It measures the elasticity of the rock when the movement of the rock is constrained the rock will deform when applied to stress. Young modulus is the ratio between the stress that is applied to the rock to the strain which is the deformation in the rock. This is shown in Eqn (2.1).

$$E = \frac{Stress\ (\sigma\ )}{Strain\ \ (\epsilon)} \tag{2.1}$$

Where σ is the stress and ϵ is the strain. The relationship between the stress and strain for rocks is shown in (figure 2.2). The rock first undergo elastic deformation till it reaches the elastic limit. Then it under go plastic or ductile deformation till the rock reaches tensile failure it will start to fracture (Donaldson, et al, 2013).

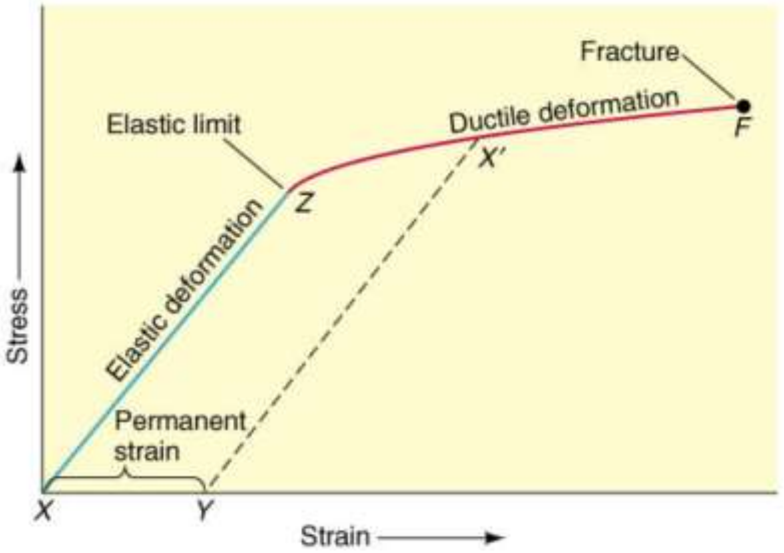


Figure 2.2: The stress vs. strain relationship (Donaldson, et al, 2013)

2.3.2 Poisson Ratio

The poisson ratio is a ratio that relates the vertical and the horizontal strain. Basically, assuming a cylindrical rock body undergo a vertical stress, the poisson ratio is the ratio between the lateral strains represented by the increase in the radius. To the axial strain represented by the reduction in length. Equation (2.2) shows the poisson ration

$$\mathrm{v} = \frac{\epsilon\,(\text{lateral})}{\epsilon(\text{axial})} \tag{2.2}$$

The poisson ratio depend mainly on the rock type and it is different for different type of rocks. The different values for Poisson ration is shown in **Appendix B.**

2.4 Formation Stress and Fracture Direction

For each formation there are three major direction for the formation stress. These stresses are the vertical overburden stress, the minimum horizontal stress and the maximum horizontal stress. These stresses are perpendicular and not equal.

The vertical stress is the most basic and is related to the depth H and the average density of the overburden formation ρ in lb/ft. The vertical stress calculation is shown in equation (2.3).

$$\sigma_v = \frac{\rho\, H}{144} \tag{2.3}$$

The minimum horizontal stress is related to the vertical stress by Poisson ration as shown in equation (2.4)

$$\sigma_h = \frac{\mathrm{v}}{1-\mathrm{v}}\,\sigma_v \tag{2.4}$$

Due to the tectonic activities of the formation the horizontal stress is not constant. The maximum horizontal stress is the submission of the horizontal stress plus the stress from the tectonic activities as shown in equation (2.5)

$$\sigma_{h,max} = \sigma_{h,min} + \sigma_{tect} \tag{2.5}$$

The calculation of this stresses is very important for the determination of the fracture direction as the direction of the fracture is always in the path of least resistance meaning in the direction of the minimum stress. Also these stresses plays a crucial rule in the determination of proppant type.

2.5 Proppant Selection for Fracture Design

The usage of proppant is to maintain the fracture open even after the decrease in the pressure after the fracturing process is done. Proppants provide a conductive pathway for the fluid in the formation to the wellbore. The proppants are evaluated based on the achieved fracture conductivity. For optimal selection of the proppant, there are a number of options to be considered such as the type of the proppant, the size of the particles and the concentration of the injected proppant (Britt, 2012; Mark, Mack, Chris & Coker, 2013).

There are different types of proppant. Generally it can be classified into sand, resin coated sand (RCS), intermediate strength proppant (ISP Ceramics) and high-strength Bauxite (HSB). The selection of the proppant type is based on the maximum proppant stress it can handle without the decrease of its conductivity. As shown in (figure 2.3), which is the plot of permeability vs the closure stress for a different types of proppant with the same average diameter. It is shown that the permeability of the fracture decrease as the formation stress increase (Schubarth & Taylor, 2004).

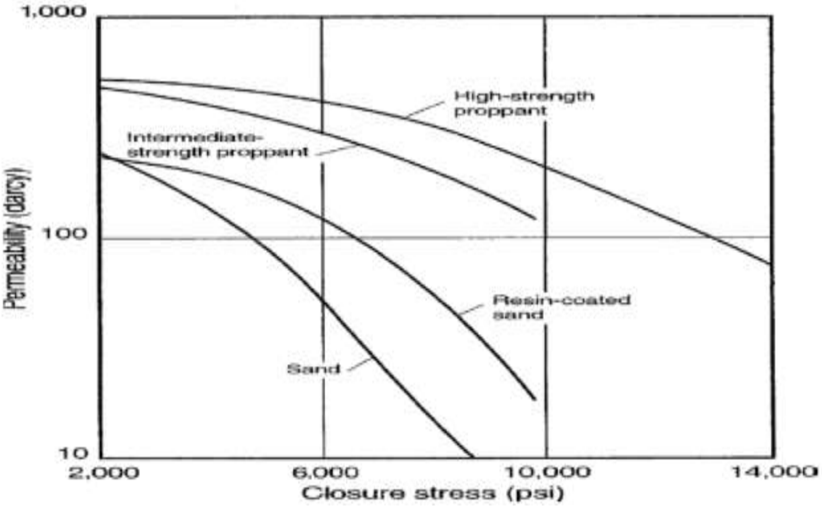


Figure 2.3: Permeability vs. Closure stress (Economides & Nolte, 2000).

In the industry, the choice of the proppant type is based on the closure pressure and sometimes the temperature. Figure 2.4 shows a schematic of how the proppant is chosen based on the industry practice

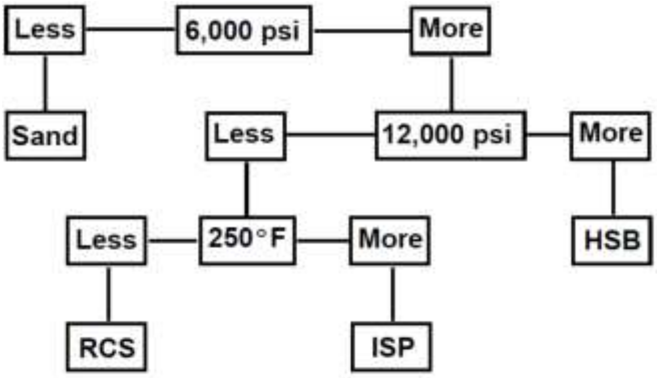


Figure 2.4: schematic of how the proppant is chosen (Donaldson, et al, 2013)

Another property for proppant selection is proppant size. Normally larger proppant means better conductivity as long as it can be transported into the fracture. However, in low permeability unconventional reservoirs where the conductivity of the fracture is not as important as fracture length, smaller proppant can be used. Larger proppant may cause bridging due to smaller perforation or fracture width. Bridging occur when the proppant particle is large enough to block the perforation or the fracture hence the proppant will end up reducing the fracture conductivity (Economides & Martin, 2007; Britt, 2012).

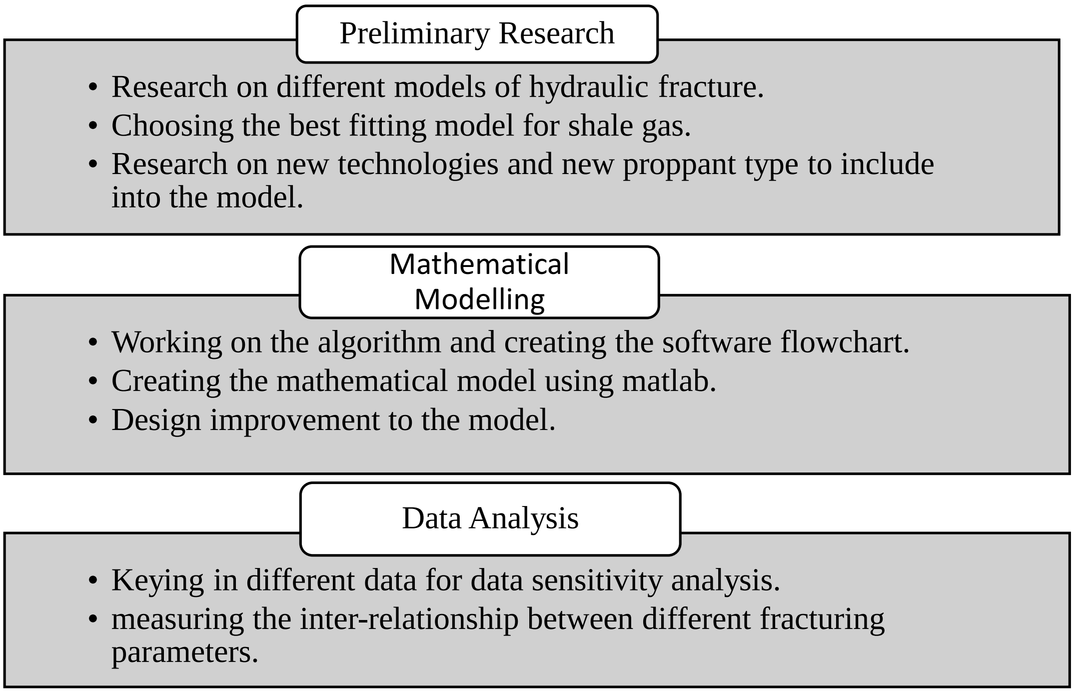
CHAPTER 3
METHODOLOGY

3.1 Research Methodology

This project is carried out based on research and mathematical model simulation using Matlab software. Different models for hydraulic fracture were studied. Then based on the literature review, the best model to represent shale gas was chosen.

This model is integrated into the matlab software by creating an algorithm through a code to calculate and determine the different parameters for hydraulic fracture for this model.

Afterwards different data were fed to the software to measure the sensitivity of the hydraulic fracture parameter. As well as determining the interrelationship between these parameters.



Preliminary Research

- Research on different models of hydraulic fracture.
- Choosing the best fitting model for shale gas.
- Research on new technologies and new proppant type to include into the model.

Mathematical Modelling

- Working on the algorithm and creating the software flowchart.
- Creating the mathematical model using matlab.
- Design improvement to the model.

Data Analysis

- Keying in different data for data sensitivity analysis.
- measuring the inter-relationship between different fracturing parameters.

Figure 3.1: Flow of the project

3.2 Gantt Chart

The gantt chart for FYP I and FYP II is indicate in Figure 3.2 and Figure 3.3

Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Selection of project title	🟩	🟩	🟩	🟩										
Preliminary research on hydraulic fracture and proppant selection				🟩	🟩	🟩								
Submission of extended proposal							🟩							
Proposal defence								🟩						
Continuation of research									🟩	🟩				
Designing the program Algorithm											🟩	🟩	🟩	
Submission of interim report														🟩

Figure 3.2: Gantt chart for FYP I

Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Creating and working on the matlab program	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩						
Submission of progress report								🟩						
Design improvement and validation									🟩	🟩	🟩	🟩		
Pre-SEDEX											🟩			
Submission of dissertation (Soft bound)												🟩		
Viva													🟩	
Submission of dissertation (Hard bound)														🟩

Figure 3.3: Gantt chart FYP II

3.3 Hydraulic Fracture Models

There are a number of models that can be used for the simulation of the hydraulic fracture such as:

- Unified Fracture Design (UFD) Model.
- Radial Fracture Model.
- Kristonovich-Geertsma-de Klerk (KGD) Model.
- Perkins-Kern-Nordgren (PKN) Model.

In this Project, the Unified Fracture design UFD is the chosen in modeling shale gas hydraulic fracture as it is used when dealing with low permeability and long fracture length.

3.3.1 Unified Fracture Design

Unified fracture design is a method developed by Economides, et al (2002) to find out the parameter for optimal design of the hydraulic fracturing process given the type and properties for proppant. It uses the properties of the proppant and reservoir and produce the optimal values for the fracture length and width.

First it defines a new dimensionless parameter which is proppant number (N_P) to include all the variables in one parameter. This parameter is defined as:

$$N_P = \frac{2\,K_f * V_p}{K * V_{res}} \tag{3.1}$$

Where K_f is the fracture permeability which is a function of the proppant type. V_p is the proppant volume that is pumped into the fracture. After calculating the proppant number, the dimensionless fracture conductivity (C_{fD}) is calculated using equation 3.2 to find the optimal half length and width of the fracture (X_f, W_f)

$$C_{fD} = \frac{N_P * Y_{eD}}{I_X{}^2} \tag{3.2}$$

Y_{eD} is the dimensionless fracture ratio and I_x is the penetration ratio.

After determining the C_{fD}, the corresponding productivity index (J) is calculated. Maximum J_D is calculated either by trial and error to get the larger J_D or by the correlation introduced by Daal and Economides (2006). In this project, the Daal and

Economides correlations are used. These correlations can be simplified in under the assumption of pseudo-steady state into the following equations J_D

If $N_P > 0.1$:

$$J_{D,max} = \frac{6}{\pi} - \exp(\frac{0.423 - 0.311\, N_P - 0.089\, {N_P}^2}{1 + 0.667\, N_P + 0.015\, {N_P}^2}) \qquad (3.3)$$

If $N_P < 0.1$:

$$J_{D,max} = \frac{1}{0.990 - 0.5 \ln N_P} \qquad (3.4)$$

C_{fD} optimum is the value corresponding to $J_{D,max}$. It indicate the dimensionless fracture conductivity that gives the maximum productivity index.

If $N_P < 0.1$:

$$C_{fD} = 1.6 \qquad (3.5)$$

If $0.1 < N_P < 10$:

$$C_{fD} = 1.6 + \exp\left(\frac{-0.583 + 1.48\, ln(N_P)}{1 + 0.142\, ln(N_P)}\right) \qquad (3.6)$$

If $N_P > 10$:

$$C_{fD} = N_P \qquad (3.7)$$

From the value of $C_{fD,opt}$, the optimum fracture width and fracture length can be calculated using the following equations

$$W_{f,opt} = \sqrt{\frac{C_{fD} * K * Vf}{Kf * h}} \qquad (3.8)$$

$$X_{f,opt} = \sqrt{\frac{k_f * V_f}{C_{fD} * K * h}} \qquad (3.9)$$

3.3.2 Fracture width , length and conductivity

Based on the unified facture design by Economides et al., (2002), optimizing the fracture width will increase the conductivity of the fracture providing selecting the right proppant.

However, in case of very low permeability reservoirs as in shale gas where the permeability is in nano Darcy. The optimization of the fracture conductivity is not as important as increasing the fracture length.

This can be expressed mathematically by using the dimensionless fracture conductivity (C_{fD}).

$$C_{fD} = \frac{K_f * W}{K * X_f} \tag{3.10}$$

It can be seen that C_{fD} is a function of fracture width, length and the permeability of the fracture and the formation.

Increasing the C_{fD} to values more than 10 or 20 will not significantly increase the conductivity as in this cases the fracture is exhibiting infinite conductivity (Britt, Smith, Haddad, Lawrence, Chipperfield, &Helman, 2006.)

In the case of shale reservoirs the formation permeability is very low which make the C_{fD} most probably more than 20. This can be explained by that the formation is loading hydrocarbon to the fracture much slower than the fracture loading to the wellbore.

3.4 Design Flowchart

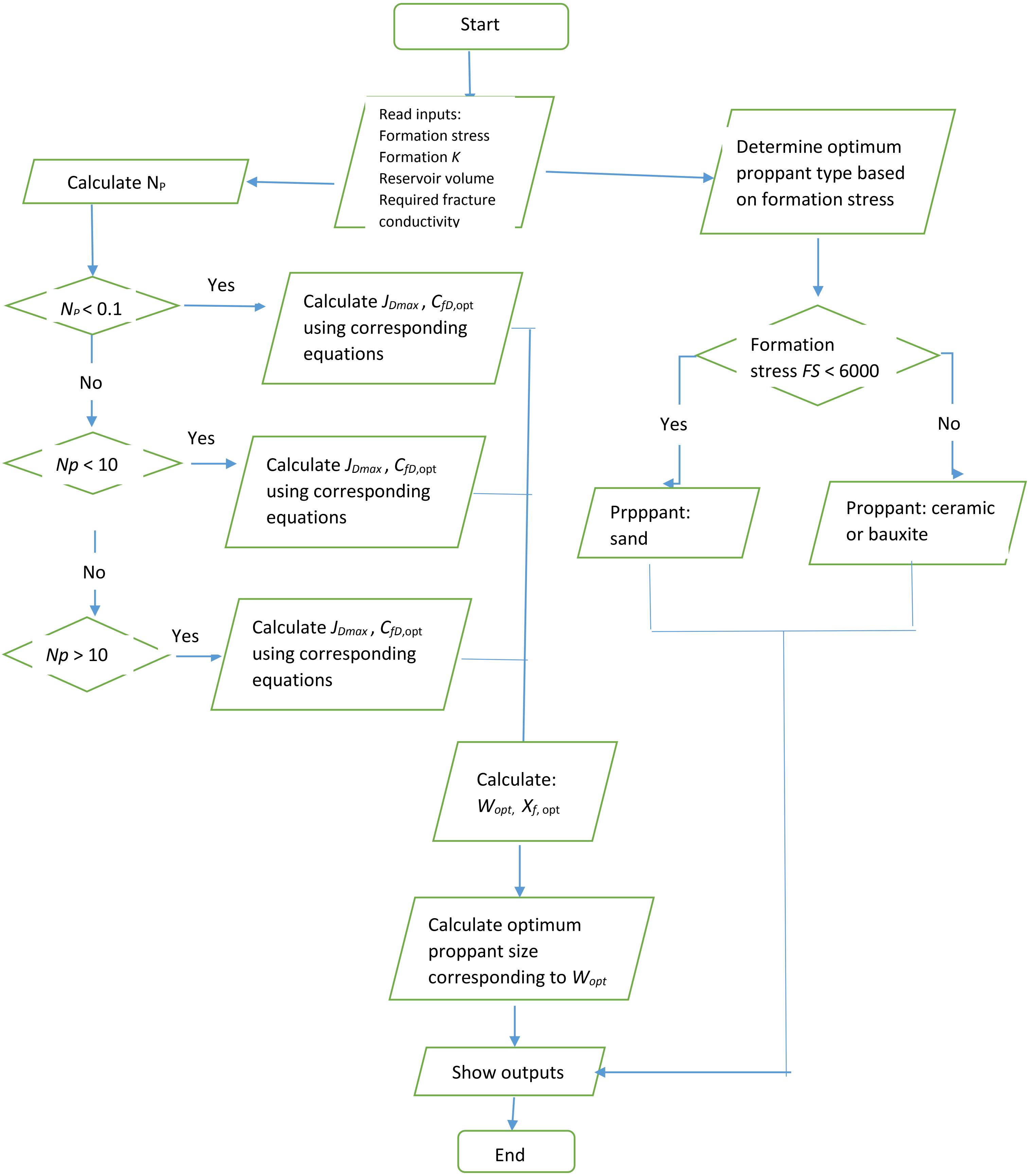


FIGURE 3.4: Software Design Flowchart

3.5 The Matlab Model

The objective of this project is an algorithm that is integrated into a matlab program for optimization of the hydraulic fracture parameter and proppant selection for shale gas reservoirs.

This program works as a black box after reading the required field inputs from the user and given data, the algorithm should calculate the optimal parameter for optimized recovery from the reservoir and then show the results. Figure 4-1 shows a schematic of the inputs and output of the matlab model

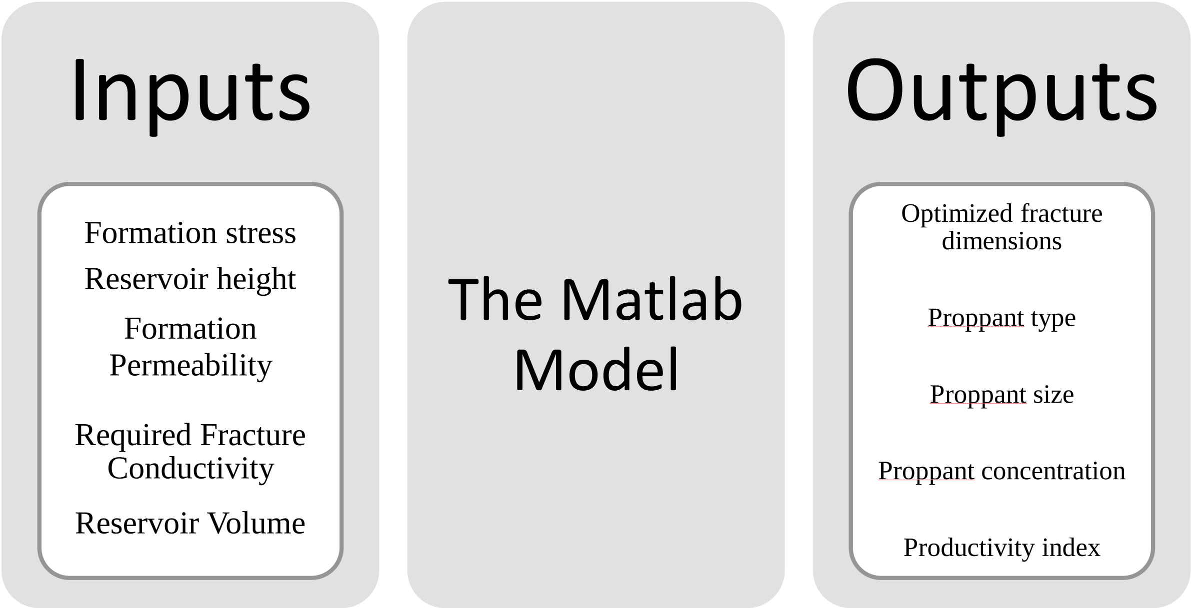


Figure 3.5: Schematic for the Inputs and Outputs of the model

CHAPTER 4
RESULTS AND DISCUSSION

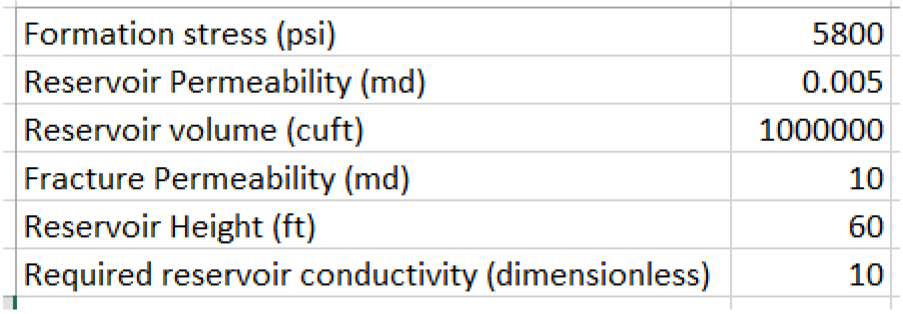
4.1 The Matlab Program

The first objective of this project is to create an algorithm to be integrated into a matlab program for optimization of the hydraulic fracture parameter. This code can be integrated to any commercial simulation software for hydraulic fracture optimization for shale gas. The code of this program is shown in **Appendix A**

4.1.1 The Inputs file

To ensure easier interface for the user, the inputs to the matlab program are keyed in an excel file. Then the program will read this inputs into the code. Using this input method facilitate the process of changing the input variable as the user does not have to change the code every time the program runs with new variables.

Figure 4.2 shows the input file for the matlab code showing all the needed inputs to the program.



Formation stress (psi)	5800
Reservoir Permeability (md)	0.005
Reservoir volume (cuft)	1000000
Fracture Permeability (md)	10
Reservoir Height (ft)	60
Required reservoir conductivity (dimensionless)	10

Figure 4.1: The Input File

4.1.2 The Processing

Referring to the matlab code in the **Appendix A**. The program first reads the inputs from the user. Then the matlab start processing the inputs.

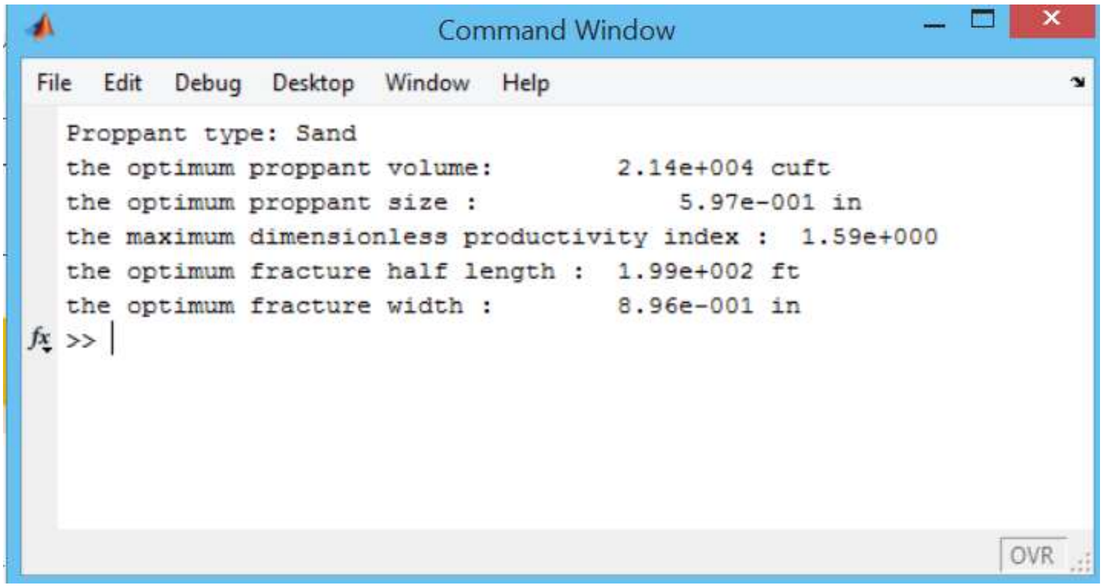
- It starts with determining the proppant type by checking the value of the formation stress.
- Then the proppant number N_P is calculated by a reverse process by using the required fracture conductivity that is read from the user. To solve the equation the matlab function "solve" is used.
- Next step is to calculate the proppant volume V_P by using the output N_P from the prior step.
- Then the maximum dimensionless productivity index is calculated using one of two equations depending on the value of the proppant number.
- The optimum fracture dimensions are then calculated using the required fracture conductivity.

4.1.3 The Output File

After processing the inputs the matlab will show a file that will include the output of the program. This file includes:

- The proppant type and the optimum proppant size.
- The total proppant volume.
- The maximum dimensionless productivity index.
- The optimum fracture half length and width.

Figure 4.2 shows the output file looks like. This output file corresponds with the input file in Figure 4.2



```
Proppant type: Sand
the optimum proppant volume:        2.14e+004 cuft
the optimum proppant size :            5.97e-001 in
the maximum dimensionless productivity index :  1.59e+000
the optimum fracture half length :  1.99e+002 ft
the optimum fracture width :        8.96e-001 in
>> 
```

FIGURE 4.2: The Output File

4.1.4 Discussion

Optimization of production of shale gas reservoir is a very complex process. Shale gas reservoirs are very different than conventional gas reservoir as the permeability of shale reservoirs is low making production impossible with conventional production methods.

Optimizing the hydraulic fracturing in shale gas reservoirs differs from conventional hydraulic fracture. Since in shale gas reservoirs, the dimensionless conductivity of the fracture is not as important as increasing the area of contact of the fracture with the formation represented with the fracture half length.

This software works on combining all the parameters together in a simple algorithm and relating all these parameters together by structured equations to solve for the optimum value of these parameters.

The priority of this software is the optimization of the fracture half-length (X_f) to ensure maximum contact with the formation and the dimensionless productivity index ($J_{D,max}$) to ensure highest flow rate with minimum pressure drop. Also the dimensionless fracture conductivity (C_{fD}) will be considered.

4.2 Sensitivity Analysis and Inter-Relationship

In this project, the fracture half-length and the dimensionless productivity index are the first priority to be optimized. The sensitivity of these parameters is determined by feeding the software different values for the required dimensionless fracture conductivity and measure the relationship between the proppant volume and the fracture half-length and the productivity index at different formation permeability.

4.2.1 The relationship between proppant volume and optimum fracture half-length

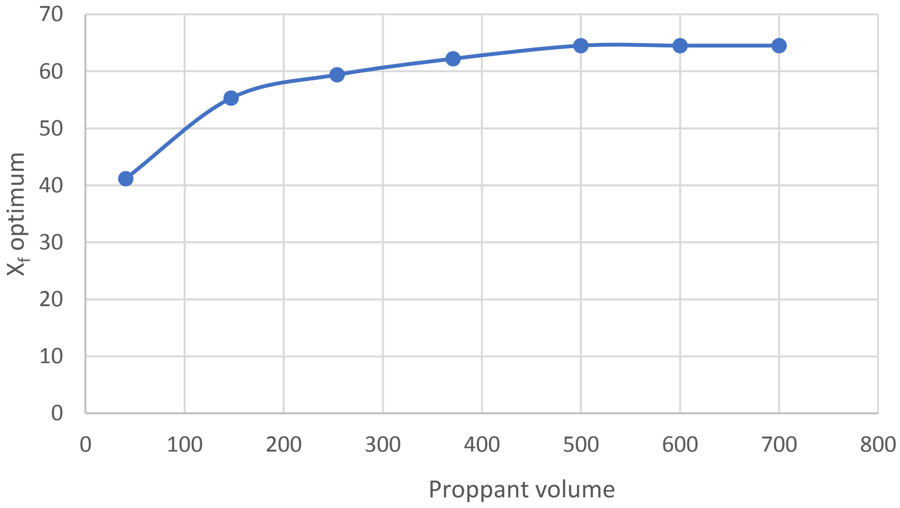


Figure 4.3: Relationship between the optimum fracture half-length and proppant volume for formation permeability of 0.001 md

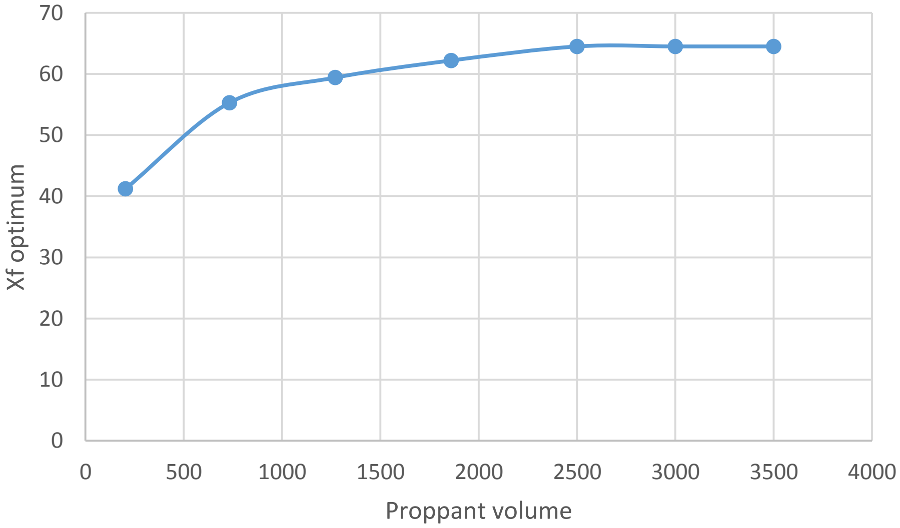


Figure 4.4: Relationship between the optimum fracture half-length and proppant volume for formation permeability of 0.005 md

Figure 4.3 and Figure 4.4 show the relationship between the injected proppant volume and the optimum facture half-length. It is seen that the optimum fracture half-length increases as the proppant volume increase. However, there is a certain point for each graph after which increasing the proppant volume will not increase the optimum fracture half-length and it is just a waste of material. This show that the optimum fracture half-length is not always the longest. However, there is an optimum fracture half -length exceeding it will not affect the optimization.

4.2.2 The relationship between dimensionless productivity index and proppant volume

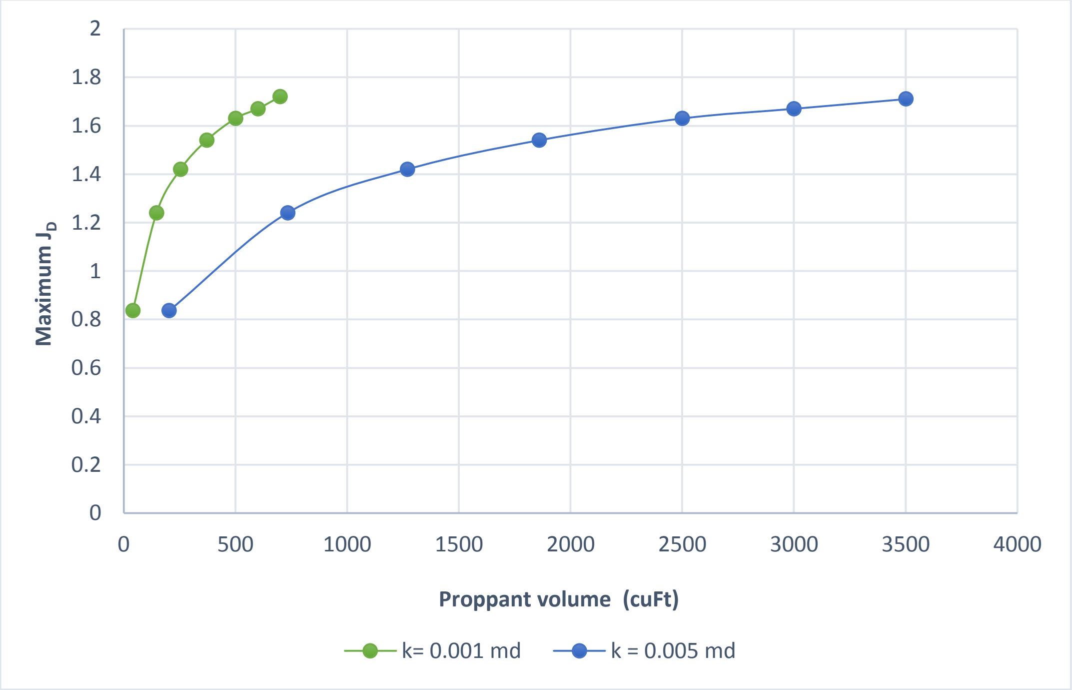


FIGURE 4.5: The relationship between maximum dimensionless productivity index and the proppant volume.

Figure 4.5 shows the relationship between the maximum dimensionless productivity index and the proppant volume. It shows that the productivity index increase as the proppant volume increase. In addition, for the same proppant volume the productivity index for the lower permeability reservoir is higher. This is related to the dimensionless fracture conductivity. As it increase when the reservoir permeability decrease.

CHAPTER 6
CONCLUSION AND RECOMMENDATIONS

This project created a mathematical model using matlab for the optimization of the hydraulic fracture process in shale gas reservoirs. Shale gas reservoirs has become one of the most important source for unconventional hydrocarbon. Besides it will be effectively replacing production from conventional reservoirs in the near future.

The whole industry is focusing on new technologies for production from non-conventional reservoirs. As the existence of easy-producing reservoirs has become more and more challenging. Any optimization for the production from shale gas even in terms of small percentage of increase of the recovery factor can be translated into huge amount of recoverable reserves.

The optimization of production from shale gas depend mostly on the optimization of fracture half-length and dimensionless productivity index. The increase in fracture half-length is desirable to ensure maximum contact with reservoir. However, for each reservoir, there is an optimum value for proppant volume. Increasing over which will not increase the fracture half-length.

The productivity index increases with the increase in the proppant volume. However, surprisingly the maximum dimensionless productivity index for the same proppant volume is higher for smaller permeability reservoirs.

It is recommended that more models for understanding shale gas hydraulic fracturing must be developed and more field-wide studies about production from shale reservoirs must be made. As shale gas reservoirs is a fertile field for new research as the global understanding for shale gas fields is still growing and new technologies and models are produced every day for better production from shale gas.

Appendix A

The Matlab Code

```
clc
clear all
clc

%reading the inputs from the excel file
input=csvread('C:\Users\Hamdi\Desktop\FYP.csv',0,1);
Fs=input(1);
K=input(2);
Vr=input(3);
Kf= input(4);
h=input (5);
%Vf=input (6);
Cfd=input(6);




%solving for the proppant type
if Fs<=6000
    fprintf ('Proppant type: Sand ')
elseif Fs< 10000
    fprintf('Proppant type: Ceramics')
else
    fprintf('Proppant type: Bauxite')
end
% solving for proppant number
syms c
if Cfd < 10
 syms Np
 eqn = subs(1.6+ exp((-0.583 + 1.48* log(Np))/(1+0.142 *log(Np)))-
c,c,Cfd);
 Np_val_2=solve(eqn,Np);
Np_val=double(Np_val_2(1));

else
        Np=Cfd;
end
% solving for the proppant volume

  Vp =  (Np_val*K*Vr)/(2*Kf);

  Vf = Vp/2;

  %solving for the optimum fracture dimentions

  Wf= sqrt((Cfd*K*Vf)/(Kf*h));

  Xf= sqrt((Kf*Vf)/(Cfd*K*h));

  %calculating the optimum proppant size
  Pd= (2/3)*Wf;
  %calculating the maximum productivity index

if Np_val <= 0.1
  Jd = 1/ (0.99- 0.5 *log (Np_val));
```

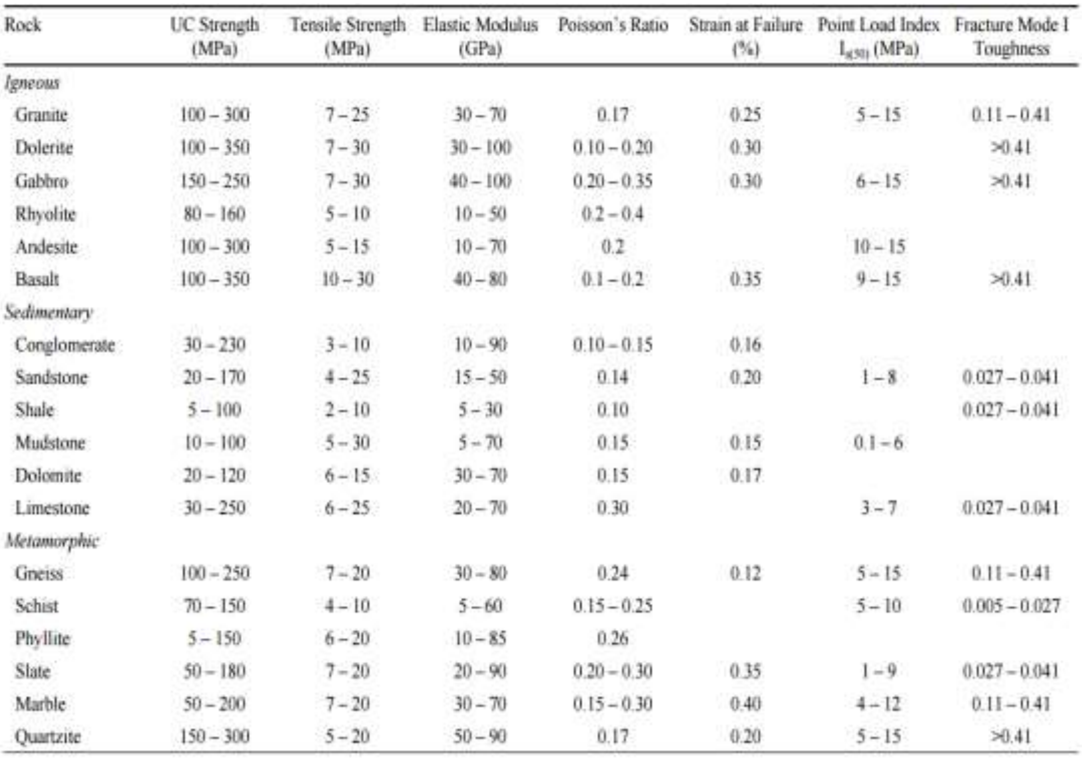
```
elseif Np_val>0.1
        Jd= (6/pi)- exp((0.423-0.311*Np_val-
0.089*(Np_val^2))/(1+0.667*Np_val+0.015*(Np_val^2)));

end

fprintf('\nthe optimized proppant volume:\t\t%2.2d cuft',Vp)
fprintf('\nthe optimum propand size : \t\t\t%2.2d in',Pd)
fprintf('\nthe maximum dimensionless productivity index
:\t%2.2d',Jd)
fprintf('\nthe optimum fracture half length :\t%2.2d ft',Xf)
fprintf('\nthe optimum fracture width : \t\t%2.2d in\n',Wf)
```

Appendix B

The Rock Mechanical Properties (Economides, Hill & Ehlig, 1994)



Rock	UC Strength (MPa)	Tensile Strength (MPa)	Elastic Modulus (GPa)	Poisson's Ratio	Strain at Failure (%)	Point Load Index $I_{s(50)}$ (MPa)	Fracture Mode I Toughness
Igneous							
Granite	100 – 300	7 – 25	30 – 70	0.17	0.25	5 – 15	0.11 – 0.41
Dolerite	100 – 350	7 – 30	30 – 100	0.10 – 0.20	0.30		>0.41
Gabbro	150 – 250	7 – 30	40 – 100	0.20 – 0.35	0.30	6 – 15	>0.41
Rhyolite	80 – 160	5 – 10	10 – 50	0.2 – 0.4			
Andesite	100 – 300	5 – 15	10 – 70	0.2		10 – 15	
Basalt	100 – 350	10 – 30	40 – 80	0.1 – 0.2	0.35	9 – 15	>0.41
Sedimentary							
Conglomerate	30 – 230	3 – 10	10 – 90	0.10 – 0.15	0.16		
Sandstone	20 – 170	4 – 25	15 – 50	0.14	0.20	1 – 8	0.027 – 0.041
Shale	5 – 100	2 – 10	5 – 30	0.10			0.027 – 0.041
Mudstone	10 – 100	5 – 30	5 – 70	0.15	0.15	0.1 – 6	
Dolomite	20 – 120	6 – 15	30 – 70	0.15	0.17		
Limestone	30 – 250	6 – 25	20 – 70	0.30		3 – 7	0.027 – 0.041
Metamorphic							
Gneiss	100 – 250	7 – 20	30 – 80	0.24	0.12	5 – 15	0.11 – 0.41
Schist	70 – 150	4 – 10	5 – 60	0.15 – 0.25		5 – 10	0.005 – 0.027
Phyllite	5 – 150	6 – 20	10 – 85	0.26			
Slate	50 – 180	7 – 20	20 – 90	0.20 – 0.30	0.35	1 – 9	0.027 – 0.041
Marble	50 – 200	7 – 20	30 – 70	0.15 – 0.30	0.40	4 – 12	0.11 – 0.41
Quartzite	150 – 300	5 – 20	50 – 90	0.17	0.20	5 – 15	>0.41

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