Optimization of Multi-Zone Unconventional (Shale) Gas Reservoir Using Hydraulic Fracturing Technique

F.C. Amadi, G. C. Enyi, G. G. Nasr

***Abstract*—**Hydraulic fracturing is one of the most important stimulation techniques available to the petroleum engineer to extract hydrocarbons in tight gas sandstones. It allows more oil and gas production in tight reservoirs as compared to conventional means. The main aim of the study is to optimize the hydraulic fracturing as technique and for this purpose three multi-zones layer formation is considered and fractured contemporaneously. The three zones are named as Zone1 (upper zone), Zone2 (middle zone) and Zone3 (lower zone) respectively and they all occur in shale rock.

Simulation was performed with Mfrac integrated software which gives a variety of 3D fracture options. This simulation process yielded an average fracture efficiency of 93.8%for the three respective zones and an increase of the average permeability of the rock system. An average fracture length of 909 ft with net height (propped height) of 210 ft (average) was achieved. Optimum fracturing results was also achieved with maximum fracture width of 0.379 inches at an injection rate of 13.01 bpm with 17995 Mscf of gas production.

***Keywords*—**Hydraulic fracturing, Mfrac, Optimisation, Tight reservoir.

I. Introduction

OPEC has predicted accelerated demand growth in 2015 for several months now, compared to the 960,000 barrels per day rise in 2014. Over the projection period 2010–2040, energy demand in the Reference Case increases by 60%. The share of gas, on the other hand, is expected to climb to over 29% cent by 2030, up from over 21% at the moment. Industrialised countries will continue to consume most of the energy, while the bulk of demand growth is expected to come from the Asian developing countries, in particular from the booming economies and populations of China and India, accounting for about 86% of the global demand [1]. Now to balance the demand and supply curve engineers have always tried to look for efficient ways to equalize the trend and give a constant energy supply to the world.

Vast reservoirs of natural gas and oil trapped in shale formations across the world for decades, but extraction techniques were not available and the resources remained untapped. Shale was not a considerable factor into most serious analyses of world energy prospects until the combination of two technologies—horizontal drilling and hydraulic fracturing was perfected. Advances in drilling over the past five years have transformed the world, especially America into a leading natural gas producer and potential energy exporter [2]. Now noting the advancement and the boost the shale gas has given to America, other countries are now also considering extraction of shale gas (fracking) as their prime area of extraction and are working on unconventional resources [3].

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II. Operating Strategies

In this work, multi zone formation is considered which refers to the hydrocarbon entrapment in different horizontal layers varied by few feet apart. All respective zones are in shale rock and each having the height (pay zone) of 55 ft, 68 ft and 45 ft respectively. The measured depths for zone1, 2 and 3 are 10109.6 ft, 10319.8ft and 10581.8 ft respectively with total casing measured depth of 13750 ft.

A. Phenomena Investigated

- Total Volume: 8922.81 U.S. gal.
- Wellbore Volume Reference MD: 9579.66 ft.
- Wellbore Volume Reference TVD: 9380.12 ft.
- Bottom hole treatment pressure (BHTP): 11995psi.
- The followings are the inputs summary.

TABLE I
CONTROLLING PARAMETERS FOR PROPPANT CRITERIA

Property	Value	Unit
Min of Proppant layer to prevent Briding	0	0
Min. Con/Area for propped fracture	0.48	lbm/ft^2
Embedment Con/Area	0	lbm/ft^2
Closure pressure on proppant	5000	psi

As the rock encounter non-homogeneous, compressive and anisotropic stresses, the stresses on the rock are not equal and vary in magnitude [4]. Therefore, the knowledge of magnitude and direction of principle stresses are very important before fracturing process begins. The hydraulic fracture will propagate normal/perpendicular to the minimum principle stress. For fracture-dominated flow, the pressure transient expands with a much faster rate and even to a maximum length as compared to the matrix without fractures [5].

B. Shear stimulation.

It refers to the fact that as pressure increases, it in turns increases the offset fracture and the leak off exponentially which can have serious negative effects of fluid loss. Therefore, tests like diagnostic fracture injection tests (DFITs) must be performed to prevent any unwanted results. Lastly, the factor on the list is the matching of the micro seismic patterns. It refers to the fact that the fractures must be connected to each other forming a complete un-interrupted network. To tackle this, it is solved through the porosity and permeability of the fractured rock. The fractures were expanded using the relatively high permeable rock and leading to the lesser permeable ones.

TABLE II
VALUES FOR TREATMENT SCHEDULE

	Slurry Rate (bpm)	Stage Liq Vol (U.S. gal)	Stage Type
1	39	25000	Pad
2	39	15000	Proppant
3	39	12000	Proppant
4	39	10000	Proppant
5	39	9000	Proppant
6	39	8000	Proppant
7	39	7000	Proppant
8	39	8850	Flush

TABLE III
ROCKS LITHOLOGY WITH DEPTHS (FT)

	Zone Name	TVD at bottom (ft)
1.	Overburden	8219
2.	Massive lithology	9109
3.	Dolomite	9358
4.	Upper Zone	9419
5.	Siltstone	9499
6.	Shale String	9520
7.	Middle Zone	9591
8.	Shale	9603
9.	Siltstone	9639
10	Shale	9698
11.	Siltstone	9728
12.	Lower Zone	9780
13.	Shale	10002

III. RESERVOIR SIMULATION

MFrac is an advanced comprehensive design and evaluation simulator containing a variety of options including 3D fracture geometry, auto design features, and integrated acid fracturing solutions. Fully coupled proppant transport and heat transfer routines, together with a flexible user interface and object oriented development approach, permit use of the program for fracture design. During simulation, Mfrac operates in conjunction with real-time data acquisition and display program

The fracturing of different zones was done mainly to optimize the production and get the maximum output using MFrac Design and Evaluation Simulator.

Fig. 1 shows the variation between Rate (bpm) and the Concentration (lbm/gal) against time (min). The green line sketch shows the surface concentration while the orange line sketch shows the bottom-hole concentration. The first (pad) stage took 15.26 minutes, the green line (surface concentration) starts after that. It shows the concentration being injected from the surface. As there is a time lag between the surface proppant reaching the bottom hole (approximately 5min), therefore there is a gap between the two lines. After the proppant reaches the bottom-hole the concentration of the bottom-hole graph increases. After that, both graphs follow nearly the same trend until the end when surface concentration stops because of the flush stage while the bottom-hole concentration still increases because of the time lag from top to the bottom. Lastly, the treatment finishes after 65.6 minutes.

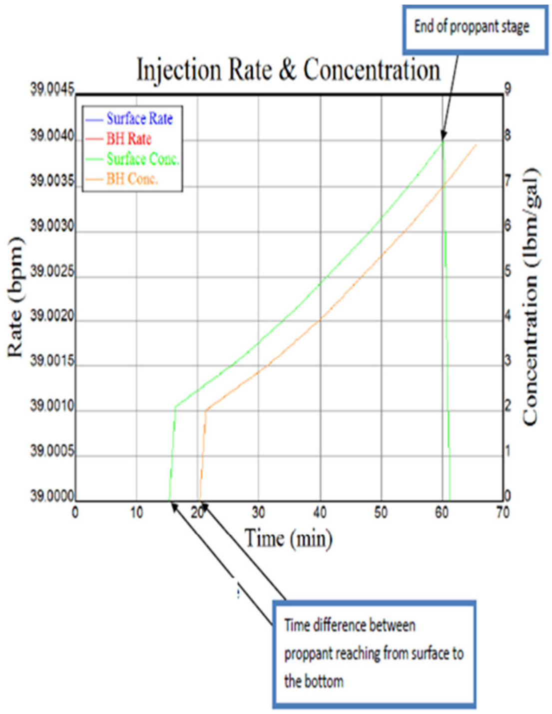

Fig. 1 Injection rate & concentration vs. Time

Fig. 2 shows the Surface and Net pressures calculated throughout the simulation. Net pressure is dependent on the in-situ stress of the rocks under consideration and pressures due to formations while surface pressure depends upon the hydrostatic pressure which in turn directs it to hydraulic power. The reason behind this lays in the fact that both hydraulic power and surface pressure depends on the weight and the concentration of the proppant. Fig. 2 shows Surface pressure and Net pressures for the entire three zones. Net pressure is dependent on the difference between the main system pressure and the opposing in-situ pressure being exerted by the rocks, and this directly relates to the width and height of fracture being created. With time Net pressure for all three zones almost follow the same path and increases due to constant increase in the net pressure. In the end, the Net pressure for Zone1, Zone2, and Zone3 were 965psi, 984psi, and 985psi respectively.

For every zone, upper height and lower height is measured with their respective maximum width. Initially, Zone 1 upper height was larger as compared to its lower height which can be noted from 50 ft till 300 ft but both got increased steadily as shown in Fig. 3. After 300 ft a slight jump came and both the values increased with a much higher rate as before till 892 ft. The main reason for this behavior is the stress which is coming from the rocks. The rock which is responsible for Zone1 difference is having a lower in-situ stress and rigidity than the other comparatively.

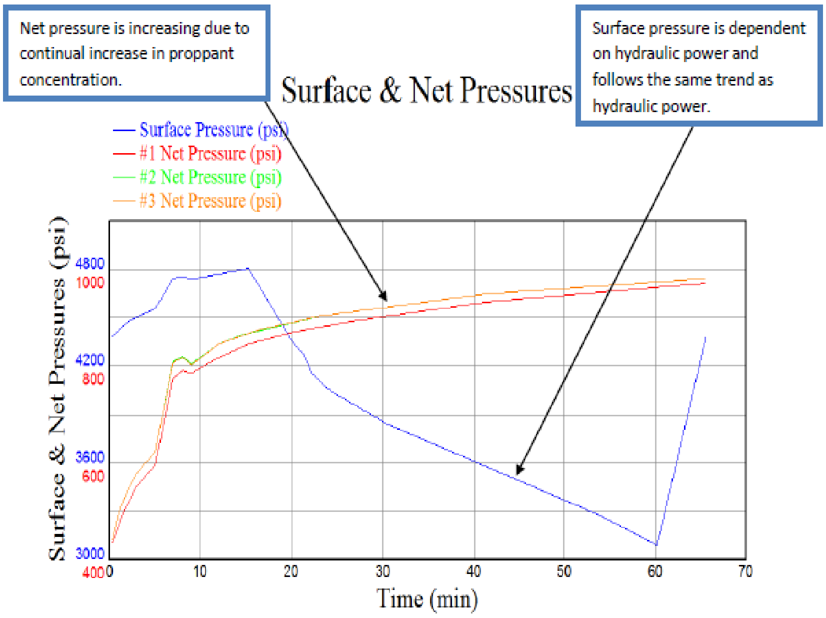

Fig. 2 Surface & Net pressure vs. Time

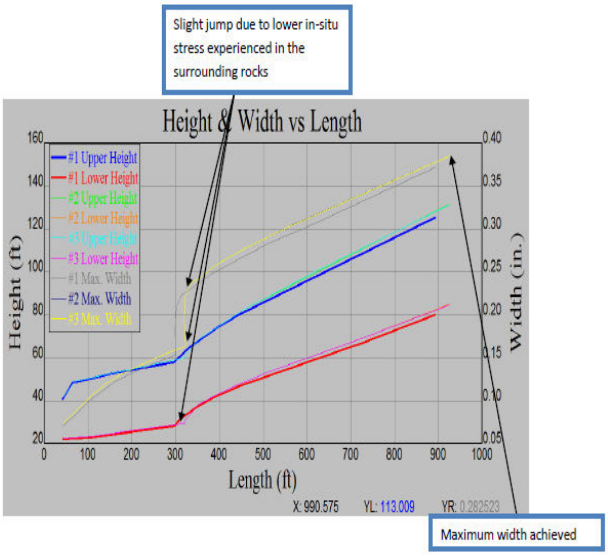

Fig. 3 Fracture height & width with length

The stress, width profiles, and width contours for Zone 1 are shown in Fig. 4. Each of the respective three zones had close proppant concentration which consequently gave the similar results for the three zones. The graph at the left most side shows the in-situ stress (psi) variation with total vertical depth TVD (in). From top in left most graph, the bar graph from 9240 ft- 9360 ft is the rock at the top of Zone1 which is dolomite having an in-situ stress of 7010 psi. Below that the lines seen as red and green is the zone in consideration which is Zone1. Zone 1 had an in-situ stress of 6100 psi. Below Zone1 is the siltstone which had an in-situ stress of 7192psi. The last bar graph below siltstone is for the shale stringer which has an in-situ stress of 7400psi. Next graph (Middle) is for width profile. The colour key shows the percentage of length being fractured: the highest width at perforation was 0.3695 in.

The width contour graph refers to the propagation fracture height vs. half-length fracture propagation. The colour scale increases from dark blue to dark red. The region between the two red horizontal lines (9360 ft- 9420 ft) shows the target Zone1 area. The dark blue region indicate the area containing the maximum fluid concentration and minimum proppant concentration leading to the lowest fracture width while as the colour key code moves towards the dark red zones it indicates the area of highest fracture width with greatest proppant concentration, to keep the prop open. Red zone in the target area shows that maximum fracture has been made in the target area which was the aim of this research work.

Fig. 5 shows the Vertical width profile. Vertical axis runs with total vertical depth (TVD) while horizontal axis runs with width (in). This figure shows the side view of the width profile. Each colour represents the percentage of fracture length created. As it gives the fracture orientation from a side it might be a bit difficult to imagine. As the graph goes wider (extends in horizontal direction) it shows the extension in width but pruning in the length propagated. Therefore, the dark blue outermost width is the highest width propagated but with the lowest of length propagated in the front. As the colour code increases from dark blue (outermost) to dark purple (innermost) this phenomenon works in the opposite manner i.e. the width propagated is minimum while the length propagated is maximum. The maximum length propagated can be seen in the center shown by a straight line. The maximum width propagated is 0.396 inches.

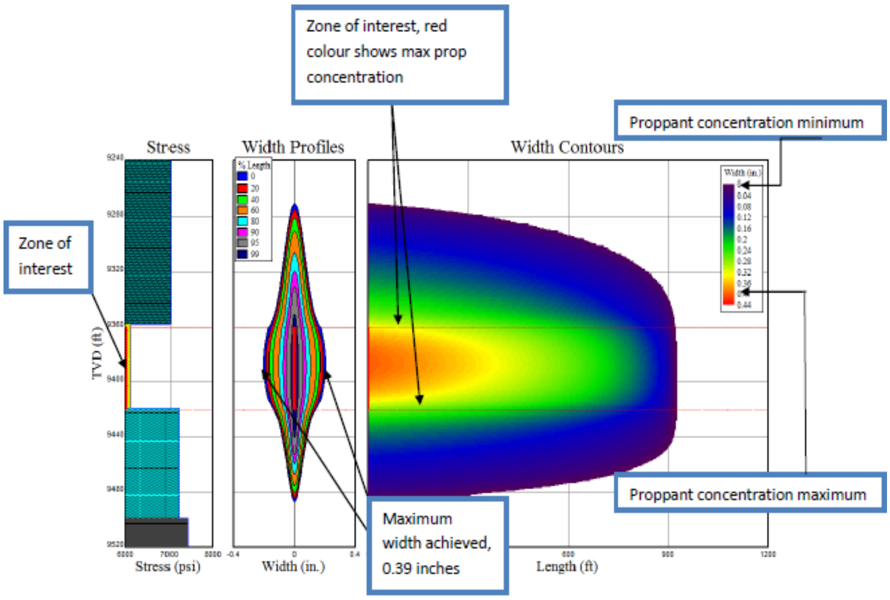

Fig. 4 Relation of in-situ stress & width

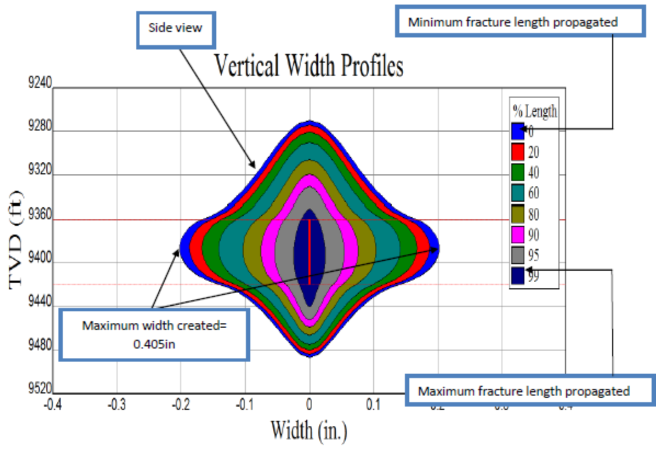

Fig. 5 Vertical width profile for Zone 1

IV. Summary of Results

After the successful simulation, the average fracture efficiency obtained was 93.8% for the three respective zones (cumulative). Average permeability of the rock system was after the completion of the treatment after 65.59minutes. This created an average fracture length of 909 ft with net height (propped height) of 210 ft (average). The maximum fracture width achieved was 0.379 inches at an injection rate of 13.01 bpm with 17995 Mscf of gas production in the end giving optimum fracturing results.

V. Discussion

This paper is aimed at production optimization in shale reservoirs. The overall key in hydraulic fracturing process is to have as high as possible contact with the rock. The more the contact with the rock the more the openings and more the potential of the rock to release its content to the well bore. In this research multi fracturing zones were considered with horizontal drilling.

It was concluded after the research that the optimization mainly depends on the following four main key parameters:

1. Fracture Geometry
2. Flow domination by the fracture
3. Shear stimulation
4. Matching micro seismic patterns

VI. Conclusion

Some of the major conclusions were noted. Following are their details:

1. A direct measure of the success of the project is to calculate the fracture efficiency. Fracture efficiency refers to the ratio of volume of fracture area created to the overall fluid volume used. In this research work the net efficiency was 94%.
2. The amount of fracture propagated is directly related to the net pressure. Net pressure results from the surrounding overburden and underlying rocks. As compared to the shale reservoir rocks these overburden and underlying rocks have a higher stress gradient.
3. The main role played by the proppant is in turn controlled by many other factors. Key factors for proppant selection which in turn affects the fracture conductivity are the proppant grain size and distribution, proppant shape, proppant strength, and the fluid flow encountered by the proppants which can be Darcy or non-Darcy.
4. Fracture conductivity (FC) is also a key point in the successful completion of the project. It is defined by the product of propped fracture width and the propping agent permeability. For the respective zones in consideration of this research, an efficiency of 94% turned out to be optimistic.

5. Fracture conductivity is controlled by the following parameters, and every effort must be done to minimize their effect. Responsible factors are as follows: Proppant embedment into the formation: Gel residue or fluid loss causing damage to the proppant: Crushing of proppant (unable to withstand the surrounding pressure): Stress corrosion directly damaging the proppant strength: constant increase in stress on the proppant.
6. Crack initiation and propagation is controlled by three main important stages. a. Stable crack initiation. b. Stable crack propagation. c. Unstable crack propagation. These all stages are dependent on the net pressure and the reservoir pore pressure.

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