A Review on Effective Hydraulic Fracturing Design: Route to the Enhanced Recovery from Unconventional Reservoirs

Amit Das[1], Zayed Bin Sultan[2]

[1]*Lecturer, Department of Petroleum and Mining Engineering, Chittagong University of Engineering & Technology*

[2]*Assistant Professor, Department of Petroleum and Mining Engineering, Chittagong University of Engineering & Technology*

Abstract- **Hydraulic fracturing is such kind of key technique that has the potentiality to extract the natural gas or oil from the unconventional reservoirs more effectively than other stimulation techniques. Moreover, hydraulic fracturing is also used for stimulating various reservoirs that was in uneconomic production previously. In addition, hydraulic fracturing is considered as a safe method for stimulating the wells as it has a lot of flexibilities in its execution. Successful hydraulic fracturing job will not be achieved until the proper design on hydraulic fracturing parameters is done. Actually this study enables to give the proper idea about the preparation of effective design parameters as well as the elementary design approaches for the hydraulic fracturing treatment. The best results from the hydraulic fracturing stimulation technique will be achieved when all the important parameters for fracturing design will be properly coordinated.**

Index terms- **Conductivity, Fracture length, Fracture width, Fracturing fluids, In-situ stress, Net pressure, Proppants, Unconventional reservoirs.**

I.INTRODUCTION

Hydraulic fracturing is a well stimulation technique which is implemented in the producing gas or oil wells to enhance the productivity as well as the recovery of that wells. This is commonly known as fracking that creates the fractures in the rock formations by using pressurized fluids for the purpose of extracting natural gas and oil. Hydraulic fracturing stimulates the oil and gas wells production and also provides the industry a prominent way to develop the recovery of the hydrocarbon resources economically. The purpose of a hydraulic fracturing is to originate a series of small pathways that increase and interconnect to the natural fractures or permeable flow paths within the reservoir and provide access of this fracture pattern to the wellbore. Hydraulic fracturing is such kind of method that is used to recuperate the hydrocarbons trapped in lower quality reservoirs i.e. unconventional reservoirs for example tight sand, shale or coal bed methane reservoirs that have the lower permeability (less than 1 md for oil and 0.01 md for gas). The switch from the conventional to the unconventional reservoirs brings about a change in grain size from coarser grained rocks with higher permeability to very fine grained rocks with lower permeability. Initially, hydraulic fracturing was combined with vertical drilling. However, this drilling technique was not suitable for unconventional shale reservoirs because many of the shale concentrations resided directly below residential or urban locations. Multiple wells then would need to be drilled to cover the area of the shale deposits in these locations. Therefore vertical drilling would not only be uneconomical but also become a local disturbance. The introduction to horizontal or directional drilling introduced a new technology to advancing natural gas production. With horizontal wells, drillers can now make a 90 degree turn in less than 100 feet as compared to the previous 2000 feet, which increases productivity to at least 2 to 3 times that of vertical wells. For this reason, hydraulic fracturing has become the most important factor in the natural gas development all over the world and when combined with horizontal drilling it has become one of the most widely used techniques for natural gas wells in the United States today. [1]

II. OBJECTIVES

The main objective of this study is the effective completion of the hydraulic fracturing design parameters. On the basis of these designed parameters, some other objectives of this stimulation technology are listed below:

- Increasing the productivity index of any gas or oil wells.
- Improving the production of the oil or gas from damaged wells.
- Facilitating the flow of fluids from the formation to the wellbore.
- Extending the amount of formation in contact with the wellbore.
- Making the better connection between the full vertical extents of a reservoir.
- Decreasing the pressure drop around the well to minimize sand production.

III. METHODOLOGY

Chemical, thermal, or hydraulic techniques are commonly used for the stimulation of the reservoir rocks. Hydraulic fracturing technique is commonly performed today to stimulate the flow of energy from the previously drilled wells. This process involves the pumping of fracturing fluids into a wellbore at adequate pressures to create fissures in the formation rock. By the injection of fluids along the isolated segments of the wellbore into the formation, the hydraulic fracturing technique allows to considerably increasing the accessible reservoir volume. The induced fracture extends until the rate of fluid loss into the formation exceeds the pumping rate during hydraulic stimulation. A propping agent (sand or ceramic spheres) is usually added to the fluid and deposited inside the fracture in order to open the fracture face.

A. THEORY OF HYDRAULIC FRACTURING

The theory behind fracturing is simply that natural gas can be extracted through porous rock mass by creating enough pressure to stimulate crack growth. This crack growth is created by sending pressurized pumping fluid through the well to average depths of 3000 meters at high flow rates to expand into existing fractures. When the drilling fluid pressure is greater than the in-situ stress of the rock mass, fracture occurs which allows the fluid to continue expanding further into the material. Some simplifying assumptions are necessary in order to create a solvable model of the hydraulic fracturing theory. The material in which the steady-state cracks growth is assumed to occur in an isotropic, homogeneous, linear elastic, impermeable body. The pressurized fluid is assumed to be an incompressible fluid acting with power-law shear thinning flow. As the pressure from the fluid rises above the combination of the lowest principal stress and the tensile strength of the soil material, tensile failure occurs. While this can happen naturally, human-controlled fractures are caused by continual pumping of the fluid into the borehole of the well. As the fluid is pumped, the pressure increases and will first fracture normal to the location and direction of smallest resistance. [2]

The size and orientation of a fracture, and the magnitude of the pressure needed to create it, are dictated by the formation’s in situ stress field. This stress field may be defined by three principal compressive stresses, which are oriented perpendiculars to each other. The magnitudes and orientations of these three principal stresses are determined by the tectonic regime in the region and by depth, pore pressure and rock properties, which determine how stress is transmitted and distributed among formations. In situ stresses control the orientation and propagation direction of hydraulic fractures. Hydraulic fractures are tensile fractures, and they open in the direction of least resistance. Horizontal fractures will occur at depths less than approximately 2000 feet because the earth’s overburden at these depths provides the least principal stress. If pressure is applied to the center of a formation under these relatively shallow conditions, the fracture is most likely to occur in the horizontal plane, because it will be easier to part the rock in this direction than in any other. In general, therefore, these fractures are parallel to the bedding plane of the formation. If the maximum principal compressive stress is the overburden stress, then the fractures are vertical, propagating parallel to the maximum horizontal stress when the fracturing pressure exceeds the minimum horizontal stress. The three principal stresses increase with depth. The rate of increase with depth defines the vertical gradient. The principal vertical stress, commonly called the overburden stress, is caused by the weight of rock overlying a measurement point. Its vertical gradient is known as the lithostatic gradient. The minimum and maximum horizontal stresses are the other two principal stresses. Their vertical gradients, which vary widely by basin and lithology, are controlled by local and regional stresses, mainly through tectonics. The weight of the fluid above a measurement point in normally pressured basins creates in situ pore pressure. The vertical gradient of pore pressure is the hydrostatic gradient. However, pore pressures within a basin may be less than or greater than normal pressures and are designated as under pressured or over pressured, respectively. [3]

IV. DESIGN FRAMEWORK

The entire fracture design depends on the following fracturing parameters:

- Fracture length (half-length, xf).
- Fracture width (w).
- Fracture conductivity (kf w).

A hydraulic fracturing design should also carry out the following procedure:[4]

- In-situ stress analysis.
- Net pressure analysis
- Fracturing Fluids Selection.
- Proppants Selection.

A. Fracture Length

There are two types of fracture length. One is created fracture length and another one is conductive fracture length. In some cases there may be a distinction between the created and conductive fracture lengths. The created fracture length relates to the length of the crack propagated during the hydraulic fracture treatment execution. The conductive fracture length refers to the length of the fracture remaining open when the well is on production, thereby effectively providing an enhanced path for fluid production to the well. In fracture design and well productivity calculations, the conductive length is assumed to consist of two equal half-lengths, xf, extending in opposite directions from the well. An expression for the fracture half-length is given by the following:

$$x_f = \sqrt{(k_f * V_f / 2C_{fd} * k * h_f)} \qquad (1)$$

Where k_f is fracture permeability, V_f is a fracture volume, C_{fd} is a fracture dimensionless conductivity, k is a reservoir permeability and h_f is a fracture height. [5]

The fracture half-length depends on the type of formations to be stimulated. This is illustrated in Figure I where fracture half-length is plotted on the y-axis while in-situ gas permeability is plotted on the x-axis. It can be seen from Figure I that the tighter the formation is, the longer a fracture can be justified.

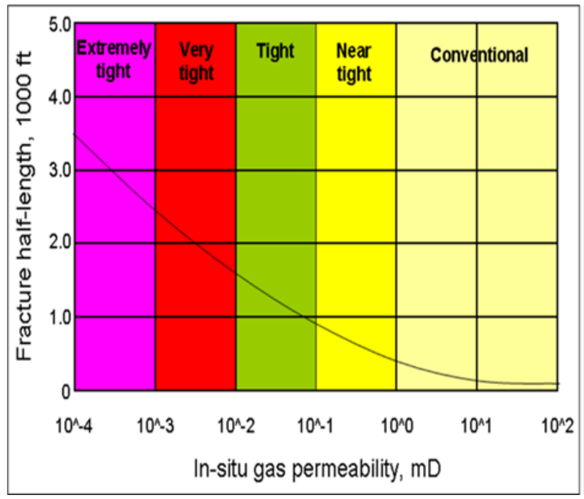

Fig I: Fracture half-length for different formations (Zolotukhin et al. 2005). [4]

B. Fracture width

Fracture width is another most important design parameter for the hydraulic fracturing stimulation technique. Proper design of the hydraulic fracturing width also leads to the desired success of hydraulic fracturing operation. There are some models developed that applied to design the fracture width more accurately. The most widely used models among them are given following: [5]

- Hydraulic fracture width with Perkins, Kern and Nordgren model or PKN model.
- Hydraulic fracture width with Khirstianovic(h) and Zheltov, Geertsma and de Klerk model or KGD model.
- Hydraulic fracture width with Radial Model.

1) Hydraulic fracture width with PKN model:

In PKN model the maximum width is at the centerline of this ellipse, with zero width at the top and bottom. For a Newtonian fluid, the maximum width, when the fracture half-length is equal to xf, is given (in coherent units and for a Newtonian fluid) by

$$w_{max} = 3.27 \sqrt[4]{\left[\frac{q_i\,\mu x_f}{E'}\right]} \qquad (2)$$

The average width in oil field units in inch, is given by

$$\overline{w} = 0.19 \sqrt[4]{\left[\frac{q_i\,\mu x_f}{E'}\right]} \qquad (3)$$

2) Hydraulic Fracture Width with KGD Model:
The KGD model is particularly applicable to approximate the geometry of fractures where $h_f >> x_f$. Thus, it should not be used in cases where long fracture lengths are generated. The shape of the KGD fracture implies equal width along the wellbore, in contrast to the elliptical shape (at the wellbore) of the PKN model. This width profile results in larger fracture volumes when using the KGD model instead of the PKN model for a given fracture length.

$$\overline{w} = 2.70 \sqrt[4]{\left[\frac{q_i\,\mu x_f^2}{E' h_f}\right]} * \frac{\pi}{4} \qquad (4)$$

And in oil field units, with $\overline{w}$ in inch,

$$\overline{w} = 0.34 \sqrt[4]{\left[\frac{q_i\,\mu x_f^2}{E' h_f}\right]} * \frac{\pi}{4} \qquad (5)$$

3) Hydraulic Fracture Width with the Radial Model:
When relatively small fracture treatments are applied in thick reservoirs or information with little stress contract between layers to retard the vertical fracture growth, this circular geometry may persist throughout the entire fracturing process. Fractures of this nature are called radial or penny-shaped fractures. For this fracture geometry, the maximum fracture width is given by

$$w_{max} = 2 \sqrt[4]{\left[\frac{q_i\,\mu(1-\upsilon)R}{G}\right]} \qquad (6)$$

C. Fracture Conductivity

The fracture conductivity is the product of the fracture permeability, kf, and the fracture width, w. Fracture conductivity, C_{fd} is also the most important factor in the design of hydraulic fracturing. Fracture conductivity is necessary to achieve maximum production rates. When the fracture length increases, the productivity of the well is also increasing. But this increasing tends to slow down if the fracture conductivity is below the threshold value of primary fracture conductivity. So, the longer the fracture length, the higher the fracture conductivity to deliver more gas or oil from the unconventional reservoirs in which the primary fracture conductivity exceeds it threshold value.

Where q_i is the injection rate, μ is the apparent fracturing fluid viscosity and E' is the strain modulus

Agarawal, Gardner, Kleinsteiber, and Fussell (1979) and Cinco-Ley and Samaniego (1981) introduced the fracture dimensionless conductivity, C_{fd}, which is exactly the following:

$$C_{fd} = \frac{k_f\,w}{k\,x_f} \qquad (7)$$

Where, k is a reservoir permeability and k_f is a fracture permeability. [5]

D. In-situ Stress Analysis

The in situ stress caused by the weight of the overburden formation in the vertical direction is given by the following expression as

$$\sigma_v = \frac{\rho\,H}{144} \qquad (8)$$

Where, σ_v is overburden stress, ρ is average density of overburden formation and H is depth.

The contact stress between grains is called effective stress. The expression for effective vertical stress is given by,

$$\sigma_v' = \sigma_v - \alpha P_p \qquad (9)$$

Where σ_v' is effective vertical stress, α is Biot's poro-elastic constant and P_p is pore pressure.

The effective horizontal stress, σ_h' is expressed as following:

$$\sigma_h' = \frac{\upsilon}{1-\upsilon}\sigma_v' \qquad (10)$$

Where υ is Poison's ratio. Now the total horizontal stress is then expressed as

$$\sigma_h = \sigma_h' + \alpha P_p \qquad (11)$$

The magnitude of the horizontal stress may vary with direction because of the tectonic effect. The maximum horizontal stress may be given by,

$$\sigma_{h,max} = \sigma_{h,min} + \sigma_{tect} \qquad (12)$$

Where σ_{tect} is called tectonic stress. Based on a failure criterion, Terzaghi presented the following expression for the breakdown pressure (Guo et al. 2007):

$$P_{bd} = 3\sigma_{h,min} - \sigma_{h,max} + T_0 - P_p \qquad (13)$$

Where P_{bd} is breakdown pressure and $\sigma_{h,min}$ is minimum horizontal stress, $\sigma_{h,max}$ is maximum horizontal stress and T_0 is tensile strength of rock material. The breakdown pressure or formation fracturing pressure is necessary to predict the breakdown pressure of the formation. Knowledge of the stresses in a reservoir is needed to get information about this breakdown pressure or fracture initialization pressure. [4]

Within the scope of high horizontal stress difference, hydraulic fracture is a dominating fracture with random multiple branches. Within the scope of low horizontal stress difference, the hydraulic fracture is partly vertical, planar fracture with branches.

E. Net Pressure Analysis

Net pressure is defined as the pressure in the fracture minus the in-situ stress. Monitoring the net pressure in real time is a mandatory part of hydraulic fracturing operations. The classic paper of Nolte and Smith can be used to interpret net-pressure behavior in the field or after the treatment to determine estimates of fracture growth patterns. Their analysis method uses the Perkins-Kern-Nordgren (PKN) theory, which assumes that as long as the fracture height is contained, the net pressure will increase with time according to

$$p_n \propto \Delta t^E \qquad (14)$$

Where 1/8 < E < 1/5 and slope E = 1/5 for low leakoff and 1/8 for high leakoff. [5]

F. Fracturing Fluids Selection

The fracturing fluid must have certain physical and chemical properties to achieve successful stimulation.

- It should be compatible with the formation material.
- It should be compatible with the formation fluids.
- It should be capable of suspending proppants and transporting them deep into the fracture but should not carry it back during flow back.
- It should be capable through its inherent viscosity to develop the necessary fracture width to accept proppants or to allow deep acid penetration.
- It should be an efficient fluid (i.e. have low fluid loss).
- It should be easy to remove from the formation.
- It should have low friction pressure.
- Preparation of the fluid should be simple and easy to perform in the field.
- It should be stable so that it will remain its viscosity throughout the treatment.
- The fracturing fluid should be cost-effective. [4]

G. Proppants Selection

Proppants are solid substances suspended in fracturing fluid to serve dual purposes of keeping the newly formed fractures open and increasing the conductivity. Proppant as small spheres transfers with the fracturing fluid to be deposited inside the fracture and keep it open at the end of the hydraulic fracturing treatment. These small spheres must be strength enough to withstand the high temperatures and pressures associated with a fracture. The following general guidelines may be used to select the proppants based on strength and cost:

- Low strength proppant- closure stresses less than 6000 psi.
- Intermediate strength proppant (ISP)- closure stresses greater than 5,000 psi but less than 10,000 psi.
- High strength proppant- closure stresses at or greater than 10,000 psi. [6]

V. CONCLUSION

In this paper, it is clear that there is nothing but understand the mechanisms of hydraulic fracturing with complex geological structures and stress conditions. Hydraulic fracturing is the most effective technology to produce natural gas and oil from the unconventional reservoirs such as hydrocarbon bearing shale formations, coalbed methane (CBM) formations and other tight formations with very low natural porosity and permeability. Without the use of this advanced stimulation technology, a major proportion of unconventional hydrocarbon resources will not able to be technically or economically extracted. . It is important but hard to predict how the fracturing will evolve under complex geological settings. Moreover it is necessary to take a proper control with caution of this technology because hydraulic fracturing always covers a large scope as well as meet different structure of rocks and endure various stress conditions. So for utilizing the best fit of this technology there should be effective design of the hydraulic fracturing parameters that results in the enhanced recovery from the unconventional reservoirs.

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