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Impact of Fracturing and Drainage-Wide Production on Tight Gas Reservoir

M.H. Farooqui (NED University of Engineering & Technology), M.S. Qamar (NED University of Engineering & Technology) & O. Ahsan* (NED University of Engineering & Technology)

SUMMARY

Hydraulic fracturing has been established as perhaps the most compelling and attractive production enhancement technique for both conventional and tight gas reservoirs. However number of formation evaluation considerations must be accounted such as the location and distance of water and hydrocarbon contacts, layering and other barriers which could limit achievable production results.

Fracturing increases well potential as well as recovery when compared to un-fractured well. Orientation of a fractured well in relation to other wells plays a significant role in optimizing rate and recovery. The flow in a fractured formation is linear and its duration will increase as the stimulation level increases. At the limit, only linear flow is seen for a fully penetrating fracture in pseudo steady state well drainage, with adequate fracture conductivity.

This study focuses on fracture geometry, number of fractures, fracture spacing, half length, well configuration, well location, the impact of fracture geometry on enhanced recovery and aspect ratio.

On the basis of study (within the study limitations), we conclude that • Fractured horizontal wells are more attractive in tight gas reservoirs than vertical fractured wells and • Use of rectangular patterns in field development combined with hydraulic fracturing creates the potential for larger JDs and recovery.

Introduction

A non-fractured horizontal well is often not economically attractive in tight gas reservoirs. Productivity of tight gas formation is strongly tied to flow area. Tight hydrocarbon bearing formations are usually fractured to accelerate production. Fracture length and conductivity are designed to optimize the well productivity. This paper will focus on impact of fracture geometry, fractured well configuration, fracture spacing and given a certain drainage area for the reservoir, how should it be divided among fractured wells for production enhancement. Fracturing increases well potential and, in some cases, recovery when compared to an un-fractured well. When a well is hydraulically fractured, there will be an introduction of linear formation flow; where otherwise there would be radial flow. Because well stimulation increases the length and duration of linear flow, optimal well placement during development planning should look to accommodate and enhance linear flow. The optimization criteria for a given development plan is to deliver the maximum production and recovery with the minimum number of wells. With longer fractures providing linear flow, the optimization of rate and recovery leads the development to rectangular drainage shapes. There is an optimal aspect ratio for the rectangular drainage shape, which is introduced later in this paper.

Why Choose a Fractured Horizontal Well

A comparison of fractured horizontal well (6 fractures) and fractured vertical well (6 fractures) is performed as shown in the Fig-1 and Fig-2. Vertical wells are insufficient in producing substantial amount of gas from tight gas reservoirs. In contrast, horizontal wells are able to reach a greater contact area with the reservoir which increases the production. Fig-1 is showing that how the production can be increased as much as 5 times more with horizontal well in comparison to vertical well.

Effect of Number of Fractures, Fracture Spacing & Fracture Half Length (X_f) on Cumulative Production

The number of the transverse hydraulic fractures needs to be optimized due to the high cost. The optimum number of fractures can be determined by observing the production rate increment with each additional fracture. To show this effect, single well simulation with 4, 5, 6 and 8 fractures are performed. Simulation results showed that increasing the number of fractures doesn't always increases cumulative production at the same rate. As shown in Fig-3, with the increase in number of fractures, the rate at which cumulative production increases, doesn't remain the same but decreases with increasing number of fractures. So for the selection of number of fractures, rate of increment in cumulative production must keep in account.

This study shows that with equal number of fractures cumulative production from a horizontal well can be increased by increasing the spacing between fractures. To show this effect, single well simulation with 6 fractures and fracture spacing of 225ft, 450ft and 900ft are performed. As shown in Fig-4 that, with six fractures cumulative production has increased significantly by increasing the spacing between fractures. Larger half lengths are always attractive in TGR. To show this effect single well simulation with 5 fractures and fracture half lengths of 30m, 60m and 100m are performed. The cumulative production results shows increment in the cumulative production with gradual increase in the value of X_f (as shown in Fig-5).

Field Development Strategy for Maximum Productivity Index (Aspect Ratio & Type Curves)

With increase in length and duration of linear flow after stimulation, optimal well placement during development planning should look to accommodate and enhance linear flow. The optimization criteria for a given development plan is to deliver the maximum production and recovery with the minimum number of wells. With longer fractures providing linear flow, the optimization of rate and recovery leads to the development of rectangular drainage shapes. This paper presents a model to define the dimensionless productivity index of finite conductivity fractured well for steady state conditions in the rectangular shape reservoir. M. Economides and P. Valko introduced an optimization technique to maximize dimensionless productivity index (J_D). They introduced new dimensionless value, proppant number (N_{prop}):

$$N_p = Ix^2 C_{fD} = \frac{2k_f I}{kV_{res}}$$

They found that for a given value of proppant number there is optimal dimensionless fracture conductivity and penetration ratio at which productivity index is maximized. Also they presented a type curve for fracturing optimization of a well in the center of square reservoir under pseudo steady state conditions.

It was found that for the same volume of proppant used in the square drainage area a rectangular shaped drainage area can give higher productivity. Since rectangular geometry provides much larger JD , it seems reasonable to consider this geometry for field development.

Let's define the aspect ratio as:

$$A_r = \frac{x_e}{y_e}$$

Where

x_e - reservoir (pattern) length & y_e - reservoir (pattern) width.

The analytical solution for fully penetrating infinite conductivity fracture in the rectangular is presented in equation below for pseudo steady state.

$$J_D = \frac{6 X_e}{\pi Y_e} = \frac{6}{\pi} * A_r$$

From inspection of the equation, since JD is proportional to aspect ratio, well productivity increases as the aspect ratio increases. From this observation it can be concluded that aspect ratios should be greater than one.

A 3D finite-difference model was developed to examine the response of fractured wells in rectangular drainage for various practical aspect ratios. The accuracy of chosen finite-difference grid and time steps were verified by analytical solutions. The type curves provide the relationship between dimensionless productivity index, fracture conductivity, proppant number and penetration ratio.

For this study, a square drainage reservoir is developed with a horizontal well in such a way that its drainage area changes from square drainage to rectangular drainage as shown in Fig-7. The pseudo steady state type curves for aspect ratios 1, 5 and 10 are shown in Figures 8 to 10.

It is evident from the Fig 8 to 10 that with the increase in aspect ratios, the dimensionless productivity index increase for the same mass of proppant used for the treatment. This concludes that keeping a rectangular drainage area for a fractured well will be more productive than a square drainage area.

Results of single well numerical simulation model with varying aspect ratios are shown in the Fig-11.

Conclusion

On the basis of study (within the study limitations), following major conclusions can be drawn,

- Fractured horizontal wells are more attractive in tight gas reservoirs than vertical fractured wells.
- Larger fracture spacing is attractive in tight gas reservoirs.
- To a certain extent, with the increase in fracture half-length the cumulative production increases.
- Use of rectangular patterns in field development combined with hydraulic fracturing creates the potential for larger JD s and recovery. The resulting economics are also better when compared to the traditional square pattern development approach.

Figure 1 Cumulative production of Horizontal and vertical well

Figure2 Gas flow rate of Horizontal and vertical well

Figure3 Effect of Number of fractures

Figure 4 Effect of fracture spacing on Cumulative production

Figure 5 Effect of increasing X_f on gas recovery

Figure6 Illustrating Aspect Ratio

Figure 7 Schematic of Multiple Fracture System

Figure 8 Pseudo Steady State Fracture Performance Type Curve. (Ar=1)

Figure 9 Pseudo Steady State Fracture Performance Type Curve. (Ar=5)

Figure 10 Pseudo Steady State Fracture Performance Type Curve. (Ar=10)

Figure 11 Effect of Aspect Ratios on Cumulative Production