Summary

Four operators drilling in the Eagle Ford Shale Play located in South Texas, USA joined Schlumberger in an initiative to acquire various types of open hole logging data in several horizontal wells, and then use the data to design the completions with optimum fracture stage and perforation cluster positioning. The wells were then evaluated with horizontal production logs to gauge the effectiveness of using the log data to engineer the completions. This paper will outline the processes used to acquire the data, the analyses made on that data, application, results and conclusion.

The study draws on previous work showing perforation cluster contribution variation in several shale plays including the Eagle Ford (Miller, 2011), and other documented results showing the effect of targeting similarly stressed rock for fracture treatments (Waters, 2011). The main objective was to improve the initial flow capacity of the well by increasing the number of perforation clusters contributing to production. Another related objective was to determine the optimal horizontal logging program that was needed to characterize the rock with minimal interruption to existing work flows. This paper will show the results of data acquired over 12 horizontal wells in the Eagle Ford Shale. Petrophysical and geomechanical analyses were based on horizontal logging measurements and used as inputs to an engineered completion design tool that generated a recommendation on each well design. The design tool grouped intervals with similar properties for stimulation treatment. Following the treatment, horizontal production logs were run through the zones to measure the perforation cluster contribution.

The results of the study have the potential to change the way Unconventional Resources are developed. Recent trends have seen a shift away from data acquisition to blind geometrical fracturing. This paper examines the value of acquiring petrophysical data in the lateral section and its application to completion optimization, the minimization of wasted resources, and the impact on early production.

Introduction

Since the initial wells were drilled in the Eagle Ford in 2008 there has been a great deal of experimentation and variation in completion techniques. Figure 1 shows that the best 3 months average production for new Eagle Ford wells initially increased but has remained more or less flat for the past 5 years in spite of a massive increase in the number of wells drilled. This data suggests that a limit in the performance of current techniques has been reached. Field economics have adapted to this expectation and high efficiency factory mode drilling and completions is required to achieve acceptable returns. As a result, field development is frequently seen as an engineering project with increasing focus on efficiency and less focus on geological understanding.
Production logging studies have indicated that this approach is leading to waste (Miller, 2011). The multi-stage fracturing techniques used in today’s horizontal wells imply more reliance on limited entry fracturing to simultaneously stimulate 5 or 6 perforation clusters. A review of historical horizontal production log data showed that on average less than 64% of perforation clusters were contributing to the total well production for a sample of Eagle Ford wells in the last 2 years. So, although wells are being brought online more efficiently, it appears that there is room for improvement in the effectiveness of completions. This study aims to correct this and demonstrate that a compromise can be achieved using a minimally invasive technique to acquire fit for purpose logging data and apply that data to have a positive impact on production.

Method

The hypothesis is that in a lateral well in good reservoir quality rock with spatial variation in stress, a more effective stimulation can be achieved by grouping similarly stressed rock for treatment. This will be characterized by a reduced number of perforation clusters showing no productivity and lead to better overall recovery and drainage.

A technique was required to acquire and input data to a software tool that would automatically group rock with similar properties into fracture stages, and position perforation clusters within those stages to minimize the overall stress differential between the various sets of perforation clusters. The key inputs are reservoir quality (RQ) and completions quality (CQ). Reservoir Quality is defined as those petrophysical parameters of organic shale that makes it a viable candidate for development. The key petrophysical parameters are: organic content, thermal maturation, effective porosity, clay volume, fluid saturation and pore pressure. Completion Quality is defined by those geomechanical parameters that are required to effectively stimulate organic shale. The key geomechanical parameters are: near-wellbore and far-field stresses, mineralogy – specifically clay content and type, and the presence and orientation of natural fractures.

In order to acquire data to input to the model a compromise was required between the full range of potential measurements and a cost effective, minimally invasive technique that could be included in pre-existing workflows to allow rapid implementation.

Each of the four operating companies were requested to acquire open hole logs in 3 wells. The data sets included a quad combo – density, neutron, resistivity and sonic on all wells and additional advanced measurements in some of the wells. The quad-combo tools were deployed in a single logging run. In order to minimize the risk to the drilling operation and fit within the existing high efficiency drilling campaigns, the logging tools were conveyed on cable and pumped down through drill pipe and a through bore bit positioned close to the bottom of the well. (Reischman,
Once the tools were in place, operationally checked and prepared to acquire data, the cable was released and the data was recorded in memory through the entire lateral section as the pipe was tripped out. At the end of the survey the logging tools were recovered using wireline and the data downloaded.

Each of the four operating companies also acquired an advanced dipole sonic log with axial, azimuthal, and radial measurements either in open hole, or in cased hole on one of the wells, for the purposes of calibration and validation. Once again, in the interests of risk reduction and time constraints these tools were deployed using an innovative conveyance technique. An electrically driven down hole tractor was used to push the tools to the bottom of the well. The tractor used up to 16 drive wheels adapting to the down hole conditions based on surface readouts of its progress and successfully negotiating obstacles to reach the toe of the laterals.

The candidate wells were spread across the Eagle Ford covering the full extent of the play and providing a good sample of gas, condensate and oil rich wells (see figure 2).

The open hole log data was processed using a petrophysical model derived from Eagle Ford core data. This processing generated clay volume and effective porosity which were used as reservoir quality input parameters. For completion quality a weighted combination of clay volume and TIV stress derived from the sonic measurements from both the vertical pilot wells and horizontal data was used (see figure 4).

The participating companies submitted their initial geometric completion plans including perforation cluster spacing, shot density and design. These parameters were used to provide boundary conditions to the software limiting the final designs not to stray too far from the original geometric design in terms of overall cost. The engineered completion design tool calculates the difference between the highest and lowest values of stress at each of the perforation clusters within each stage. The clusters are then redistributed in an attempt to minimize this calculated difference. The result of moving from a geometric to an engineered design is shown in figure 3.
The optimized completions designs were then presented to the participating companies and they were given the choice whether to implement them or not. In a majority of cases they decided to complete the wells using the optimized design.

Detailed data was requested from each of the participating companies to allow a comparison of the various fracturing techniques used. The wells were fractured and put on production and allowed to flow back for approximately four to six weeks.

Production logging is widely used to assess the effectiveness of well completions and performance of various zones within the well bore. A production logging tool with an array of measurements along the vertical axis of the horizontal wellbore was used to effectively evaluate the rate contributions from each individual perforation cluster. The vertical array of production logging measurements included 6 electrical and 6 optical probes for fluid identification and phase holdup, and 5 quality mini-spinners for phase velocity and resolution not available with other production logging tools. In the interests of efficiency and lateral extent, the production logging data was acquired using a down hole tractor capable of recording data while logging down. In the course of the project over 50,000 ft. of horizontal wellbore was successfully negotiated using tractors. Multiple passes, down and up, were acquired during production logging operations along with station stops when needed. Production logging data was processed using published algorithms (Chadwick, 2011) and interpreted by the same production log analysts throughout the project (see figure 5).

Figure 3: Calculated Maximum cluster stress differential by stage
Examples

Figure 4: Example of data montage showing open hole data, processed outputs and rock assignments

Figure 5: Example of production logging data acquired on a consortium well showing the cluster contributions
Results

From published data (Miller, 2011) which analyzed over 100 production logs from multiple unconventional plays across North America it was clear that in the horizontal wells stimulated with multistage completions, there were perforations that did not contribute to the production. On average 30% of the perforation clusters do not appear to produce. For the purpose of this project 17 Eagle Ford Production logs run on geometrically spaced completions were used as the control data set (see figure 6). These 17 PL’s were run with the same type of Production Logging tool and analyzed by the same analyst using the same software, to provide a consistent base line from which to compare the Engineered approach to the Geometric completion. The average perforation efficiency is defined as the number of perforation clusters contributing to production divided by the total number of perforation clusters evaluated. For this data set 36% of the perforation clusters were considered ineffective.

From the consortium wells, at the time of writing this paper, seven wells had been successfully logged. Of the seven wells, six were engineered completions while one was left as a geometric spaced completion. The Engineered completions showed an average perforation efficiency of 82% while the base line for the 17 EF wells with geometric completions was 64%. The single control well in the consortium with geometric spaced completion did slightly better than the average with a 69% efficiency but did not have a complete production log evaluation by individual perforation cluster over the entire lateral (see figure 7).
The group also looked for trends or patterns such as: toe up versus toe down; heal versus toe production; and oil versus gas in the results but were not able to draw any clear and consistent conclusions.

Analysis of the production results from the consortium wells was undertaken using public data taken from the IHS database. The max month average production was used as an indicator for performance to allow comparison with a group of offset Eagle Ford wells within a 3 to 4 mile radius of the consortium wells. The offset well sample size density ranged from 16 to 63 wells depending on the geographic location and activity in the area. The Engineered completion wells were all above the average when compared with offset wells with five of the seven wells in the top quartile of production (ranked in top 25%). The single geometric well was below the average ranking at 60% when compared to offsets.

Conclusions

The initial hypothesis that in a lateral well a more effective stimulation can be achieved by grouping similarly stressed rock for treatment, increasing the number of perforation clusters contributing to production, has been proven. Reservoir characterization in horizontal wells is essential for more effective completions and can be achieved with low risk, cost effective petrophysical measurements and innovative conveyance techniques. Use of this data to group intervals of similar rock properties increased the number of perforation clusters contributing to production. The resulting perforation cluster efficiency was improved by 28% and wells with Engineered Completions were top quartile wells compared to their offsets.

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References


