Microseismic Monitoring of Ball Drops During a Sliding Sleeve Frac

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Summary

Ball-activated, sliding-sleeve fracports are a common completion used for horizontal wells in unconventional reservoirs. Characteristic seismic signals have been observed at approximately the same time as pressure spikes associated with balls dropped to open the sliding sleeves. The ‘ball drop’ seismic signals are high amplitude, low frequency, with multiple discrete events locating at the fracport. These seismic signals are attributed to the sleeve sliding open. The occurrence of the ball drop events can therefore be used to diagnose if the sleeve opened properly at the expected location, and along with the pressure and microseismic response can be used to validate the expected actions of the completion. Various case studies are presented illustrating examples of both successful and unsuccessful sleeve operations.

Introduction

Openhole completions using multiple, mechanically-activated, sliding-sleeve fracports is an increasingly popular design in unconventional horizontal wells (e.g., Seale and Athans, 2008). Multiple ports are deployed on tubing between isolating packers to provide hydraulic fracture stage isolation within a certain targeted section of the wellbore. Compared to limited entry methods such as plug and perf, completion costs tend to be reduced by avoiding the need for a cemented casing or liner and enabling faster fracturing operations (e.g. Lohoefer et al., 2006). Furthermore, there are also potentially more frac initiation points per stage produced a more optimal, complex fracture network compared to limited entry perforations. Typically, sleeves are opened by dropping or injecting different sized balls into the well, which fit into a corresponding sized seat at a target point in the well (e.g., Wozniak, 2010). Once seated, the balls block flow and increase back pressure that pushes open the sleeve/fracport. As with other unconventional reservoir stimulations, microseismic monitoring has been used to understand the stimulated fracture geometry and the performance of the completion. Seismic signals with characteristics seismogram characteristics have been observed associated with the ‘ball drops’ (called ‘ball drop events’ herein), which will be described in this paper and discussed with potential seismic sources associated with the operation of multiple fracport completions. The paper will also describe case studies, where these signals are used along with the microseismic and treatment data as diagnostics of the completion performance to help identify the cause of anomalous hydraulic fracture geometry and in particular the effectiveness of the completion to provide intended stage isolation.

Ball Drop Signals

Characteristic seismic signals have been observed on many projects associated with the timing of the ball drops. Figure 1 is a conceptual pressure curve associated with a ball drop and identifies various phases (Figure 2) corresponding to the opening of the fracports. The ball is pumped into the well and continues to the appropriate sized, target seat. Once seated, the pressure increases until the sleeve slides open. Once the fracport is open, the annular space will become pressurized leading to the fracture initiation in the interval between the packers. Any of the operation phases shown in Fig. 1 and 2 could potentially be associated with the source of the seismic energy, and all approximately correspond to the timing of the observed ball drop events. Note that while the microseismic data is recorded with a GPS system for accurate timing, the injection data is typically recorded with only an approximately synchronized recording clock, making detailed timing comparisons impossible. The ball drop events could be associated with many of the various mechanical actions of the completion operation. Consideration of the energy associated with each potential source, indicates that only the sleeve sliding would result in a significant seismic amplitude and hence is most likely the source of the signals.

Figure 3 shows a typical ball drop seismic signal, characterized by relatively large signal amplitudes. As illustrated in this example, there are often multiple discrete signals observed, usually within a time frame of less than a second. Fig. 3 shows three distinct signals with common p and s-wave arrivals, each with similar characteristics but variable signal amplitude. As found in this example, the first signal often tends to be the largest amplitude. For comparison, Figure 4 shows a corresponding signal of a typical microseismic event associated with the hydraulic fracture. The signal amplitude is lower as illustrated in the figure which results in the apparent relatively large noise amplitude before the signal arrival (absolute noise levels are almost identical for Fig. 3 and 4). The ball drop event has a more complex and lower frequency pulse (less than 200 Hz) compared to the microseismic event (400 Hz). Locations estimated for each of the distinct signals in the ball drop events all locate at the fracports. Ratios of P- to S-wave amplitudes are generally consistent with an axial force, and so all the observations point to sliding sleeve sliding as the source of the signals (see Maxwell et al., 2011 for additional details). As such the observation of the signals and corresponding

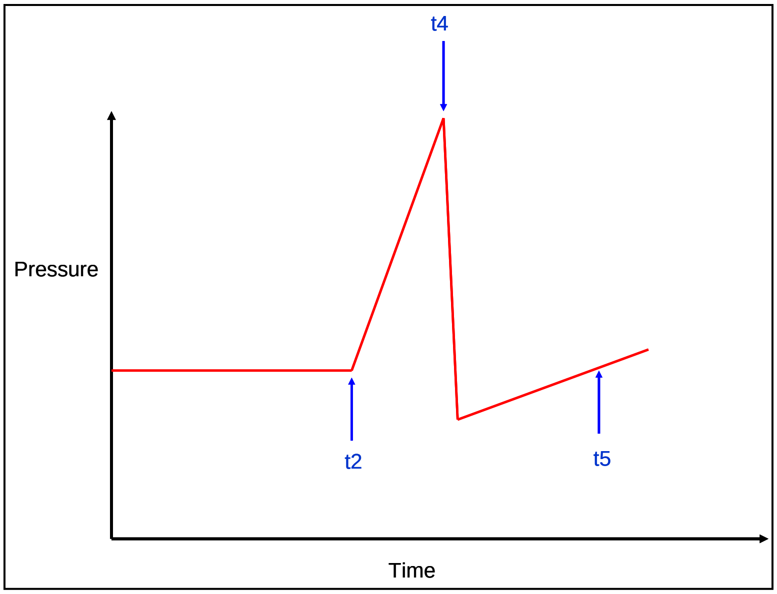

Figure 1. Conceptual pressure record associated with a ball drop. Mechanical actions at the various times are identified in Fig.2

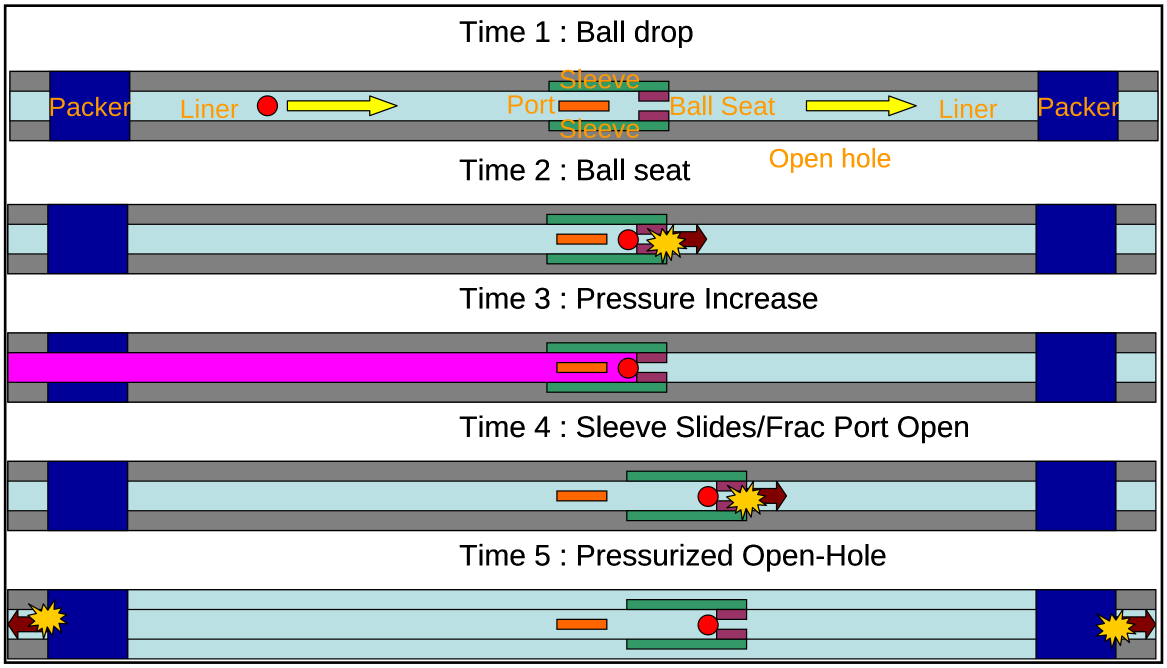

Figure 2. Mechanical actions associated with balls opening fracports. Red arrows indicate potential displacements that could result in a seismic source.

locations can be used as a diagnostic to confirm the intended sleeve operated as expected. The ball drops can also be used to orient sensors and calibrate the velocity model in the same way as perforation shot signals in a conventional completion.

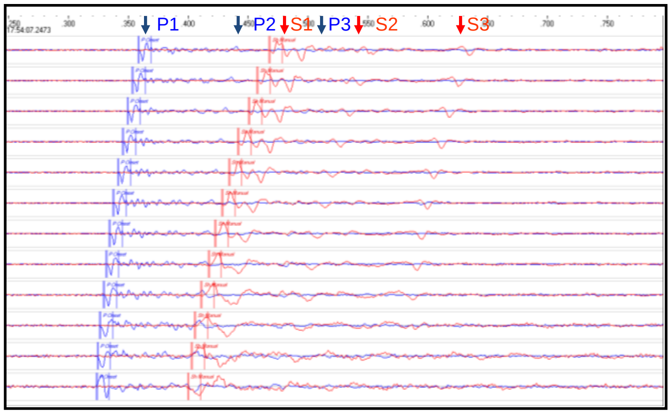

Figure 3. Typical seismic signal of a ball drop event. Three discrete signals are seen, each with a p- and s-wave combination. The first signal is picked on all levels.

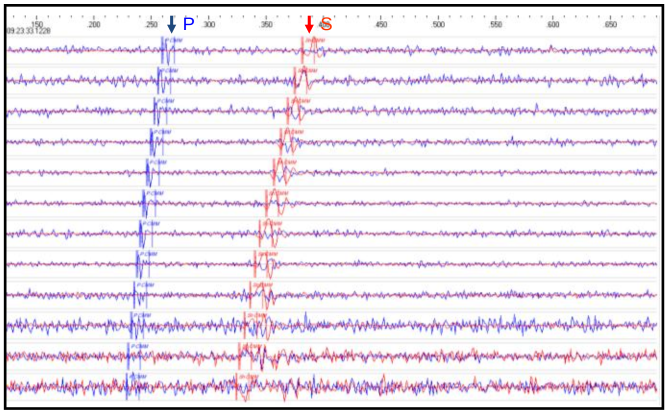

Figure 4. Typical microseismic signal, with one p- and –s-wave combination. Signal amplitude is scaled for each sensor, giving the appearance of variable noise.

Case Studies

In the first example, a multi-stage hydraulic fracture in the Cardium Sands in Alberta was monitored. Figure 5 shows the progression of three stages in the project. Note that with each stage, a ball drop event was observed and in each case was located at the fracport. The subsequent microseismic data shows an approximately NE-SW narrow trend, consistent with a relatively simple planar fracture aligned with the corresponding fracport. During the second and third of these stages, a few events are located within the microseismic region from the previous stage, which is attributed to relaxation processes and continuing but diminishing microseismic activity continuing after the previous stage. This effect is common in any microseismic project, where post-injection activity typically decays with time. In the case of these mechanical completions, the limited amount of time between stages means that often during the time period of pumping a new stage there is also remnant activity continues in the previous. Nevertheless, the ball drop events confirm the opening of the appropriate port in each stage and microseismic activity centered on each open port as expected. As such this example can be considered a successful operation of the completion.

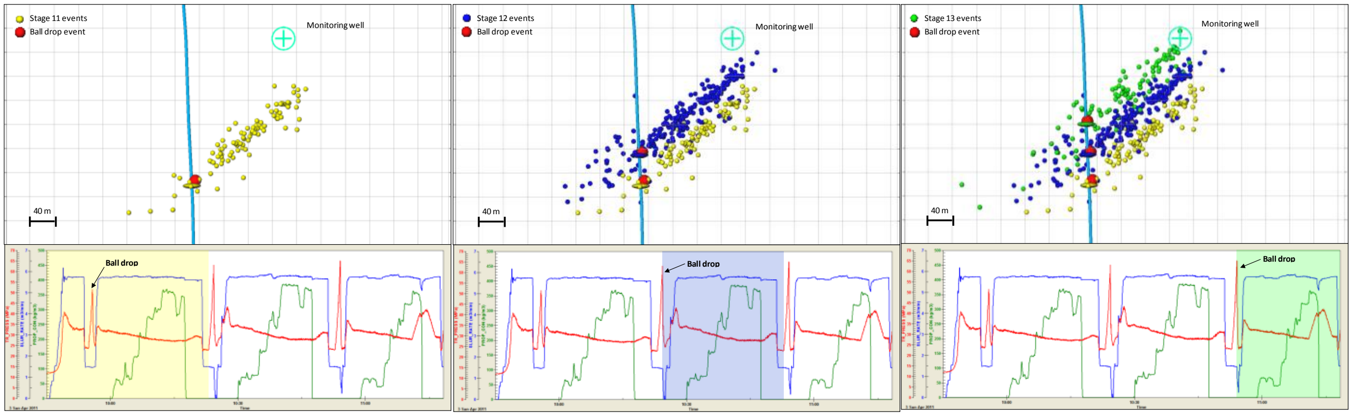

Figure 5. Three hydraulic fracture stages of a multi-stage stimulation in the Cardium sands. Ball drop events in red.

The second example is a six stage frac was performed in the Rock Creek sand, in Central Alberta. Figure 6 shows the microseismic and pumping data for the six frac stages. Stage 1 microseismic events concentrated away from the corresponding fracport, with the activity instead clustered around the stage 2 fracport. The growth of the hydraulic fracture at such a large distance along the well and past the packer separating these ports, could be related either to a fluid flow around the packer or possibly a partially opened fracport in the position of the second stage. A ball drop event was recorded at the Stage 2 fracport and the subsequent frac stage resulted in overlapping microseismic events with stage 1, highlighting poor hydraulic isolation between these first two stages. No ball drop event was observed with stage 3 and the majority of the corresponding microseismic events again overlapped with the microseismicity with the first two stages. Note the characteristic pressure spike was also not observed, so along with the lack of a ball drop event and microseismic locations suggests that the port did not open. After pumping for several minutes and examining the microseismic data in realtime, this stage was abandoned. Ball drop events were then recorded for the final three stages at the intended fracports, and the associated microseismicity recorded during the subsequent fracs clustered near each fracport. In each stage, there were a small number of microseisms locating within the cluster of the previous stages which were attributed to remnant activity as the previous hydraulic fracture continued to equilibrate. A larger total volume was pumped in the final stage and resulted in a longer hydraulic fracture as seen in Fig. 6. This case study is an example of poor hydraulic isolation during the first two stages, followed by failure to open the intended fracport during the third stage. The final three stages resulted in successful operation of the mechanical completion with intended hydraulic isolation. Realtime microseismic monitoring of the frac was performed, and allowed the operator to realize the poor hydraulic isolation and failure to open the fracport during the operation. Microseismic was the key information used to decide to abandon the failed stage 3. Obviously one advantage of access to information about the success of the completion operation during the frac is to enable modification to the fracture program to avoid for example potential screen-outs. However, the information could also

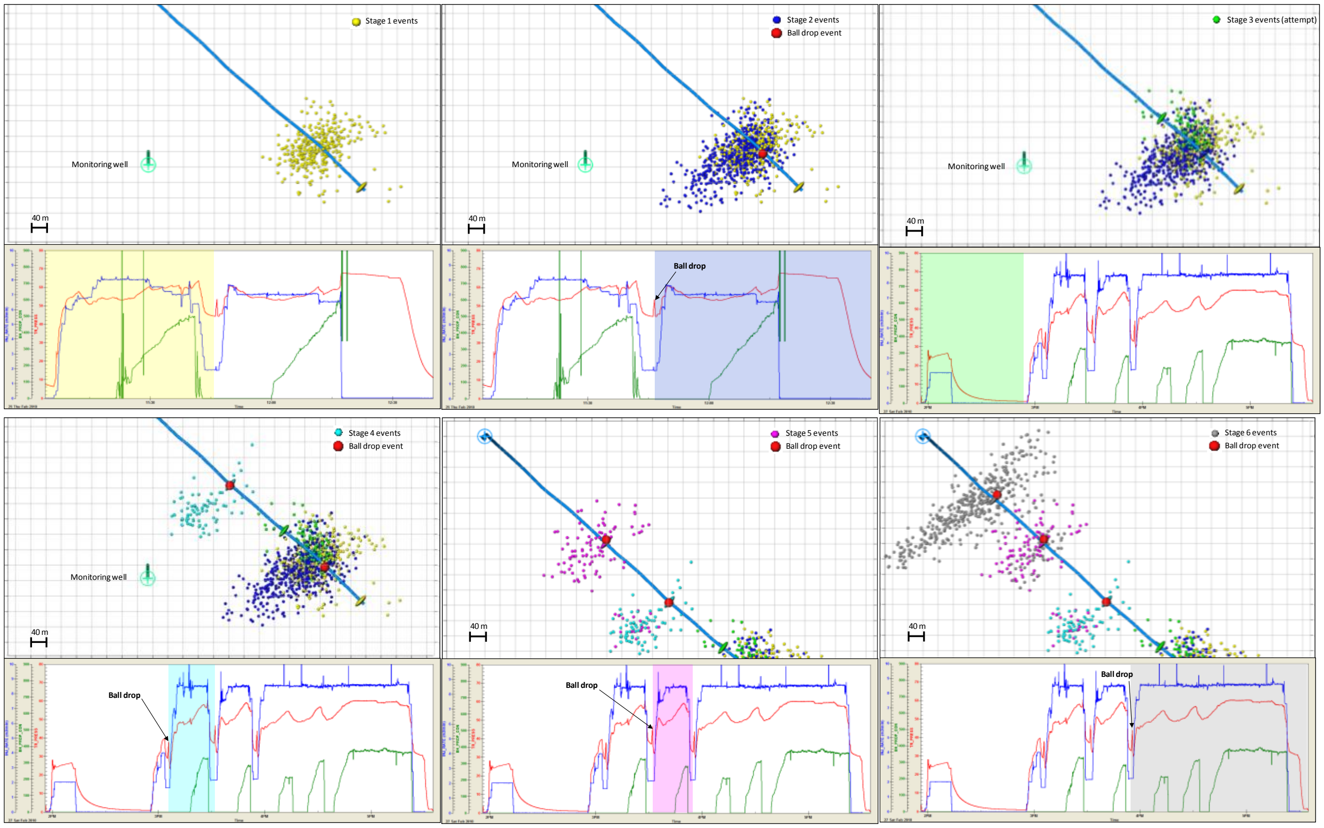

Figure 6. Six stage stimulation in the Rock Creek sands. Ball drop events in red.

potentially be used to target remedial operations on the completion in an attempt to get the completion to function as intended.

Maxwell et al., 2011 describe more details of the seismic signals along with additional case studies.

Conclusions

Characteristic seismic signals are often observed at approximately the time of balls being dropped into mechanical, multi-fracport completions. The signals are high amplitude, low frequency, repeating, complex pulses with p/sh amplitude ratios consistent with an axial displacement type source. The signals tend to locate near the fracport, and are believed to be related to the sleeves sliding to open the fracports. As such, the observation of the signals provides a diagnostic that the operation successfully opened the fracport and along with treatment and microseismic data can be used to interpret the proper operation of the completion. Case studies shown here provide examples of proper completion performance with isolated stages in the intended interval, along with an example of a fracport that failed to open. One case study also highlights the ability to use this integrated information in realtime to make on-the-fly operational decisions based on diagnosing the completion operation. Ultimately realtime microseismic information could also be used to reattempt intended mechanical actions of the completion, if the operation is not successful.

References

Lohoefer, D., Athans, J., and Seale, R., 2006, New Barnett Shale Horizontal Completion Lowers Cost and Improves Efficiency, SPE103046.

Maxwell, S.C., Chen, Z, Nizkous, I., Parker, R., Rodionov, Y., and Jones, M., 2011, Microseismic Evaluation of Stage Isolation With a Multiple-Fracport, Openhole Completion, SPE 149504.

Seale, R., and Athans, J., 2008, Effective Open Hole Horizontal Completion System for Multistage Fracturing and Stimulation, SPE114880.

Wozniak, G., 2010, Frac Sleeves: Is Milling Them Out Worth the Trouble?, SPE138322.