Keeping Connected

6 remedies to prevent casing deformation and maintain wellbore integrity for a successful completion

Casing deformation means the initial shape and integrity of the casing is lost in any phase of a well's lifecycle: completion deployment, stimulation treatment or during production.

Casing deformation is a common problem in cased hole wells with plug-and-perf completions that are hydraulically fractured at high pressure. The problem is accentuated in horizontal wells because of the shear length of the borehole and the diversity in lithology along this length. The consequences of casing failure can be significant; it can mean a very costly workover procedure if the wellbore becomes inaccessible, bypassing a few producing zones because the stage isolation plugs cannot be drilled out post-treatment, or producing through a deformed wellbore that may leak at different places during the producing life of the well causing hazardous consequences.

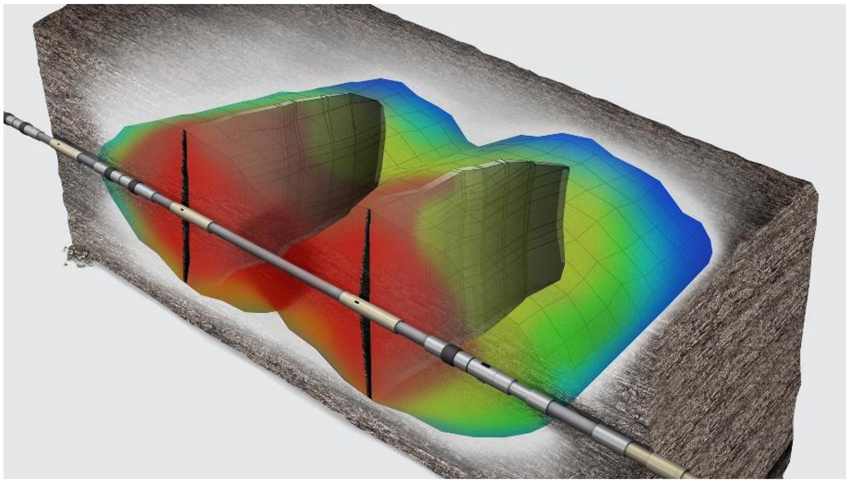
In extreme cases, it can mean complete abandonment of a well if catastrophic failure occurs above the final fracturing stage, making the wellbore totally inaccessible. A worst-case scenario is casing failure causing a blowout, which could cause injury, potential fatalities and environmental pollution.

BACKGROUND

Compared to conventional reservoirs, casing deformation and failure in tight and shale reservoirs is much more frequent and pronounced. The lithology and tightness, diverse bedding planes and changes in reservoir properties of unconventional formations require high pressure and high volume hydraulic fracturing treatments in multiple stages, sometimes in excess of 50 stages per wellbore, to ensure commercial production.

The entire hydraulic fracturing process is very complex and impacts completion assemblies and reservoir properties with abrupt changes in temperature, pressure, pumping of abrasive proppants or acid, and finally, reservoir fluids which may have corrosive effects on the casing and liner. The breakdown of the formation creates a complex fracture network. Pressure accumulates in different parts along the borehole, slips in bedding planes, and subsequently, high pressure builds against the cement of the wellbore. The high rate fluid pumped into the formation does not always completely disappear or flow back at the end of the treatment program, affecting the overall long-term production pattern. The flow regime changes in the reservoir and around the wellbore after the fracturing process.

For multi-stage fracturing, the high number of stages produce more cyclic stress on the completion system during treatment. Wells that are drilled in the minimum stress direction so that multiple independent fractures can propagate during each pumping stage will need significantly higher pressure to initiate each fracture stage and overcome near-well tortuosity effects.



Given all these dynamic changes happening during the fracturing process, the casing can deform and fail. This white paper elaborates on a few specific reasons for casing deformation, draws conclusions on possible remedies and examine results from a field study.

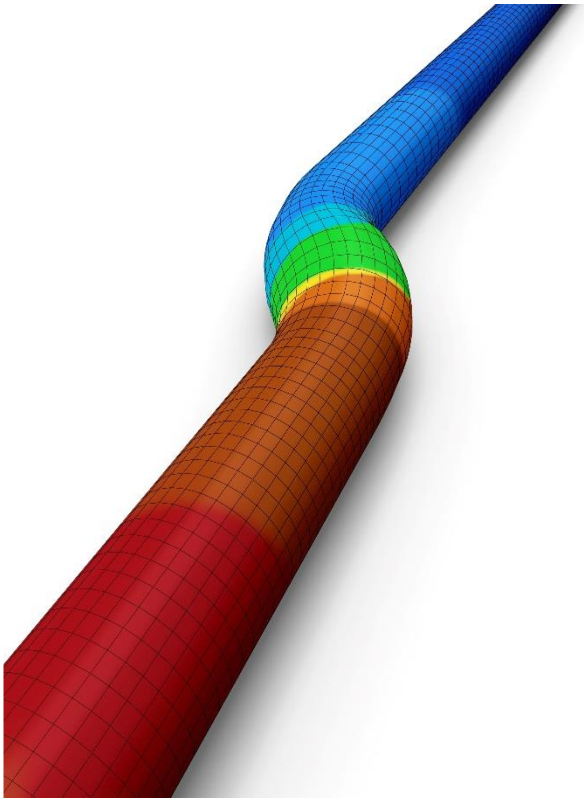
6 Potential Causes of Casing Deformation

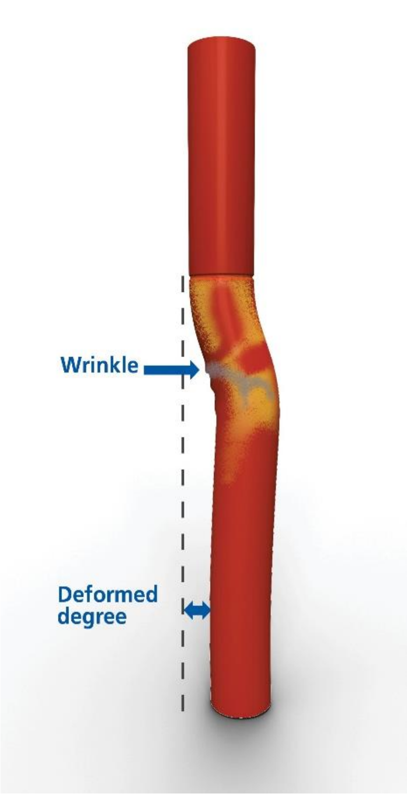
Casing Quality

Inspection and rigorous quality control of the completion material is necessary to ensure that the materials run in the borehole pass API-specified technical acceptance criteria. If casings are not customized according to the pumping and reservoir conditions or the quality of completion does not meet the required criteria, the integrity of the completion may be compromised and will negatively affect future well intervention.

Wellbore Trajectory

Drilling of long laterals is needed in tight formations to meet production expectations and reduce cost. However, long laterals with severe doglegs, which can happen in geo-steered wells where staying within the interval is the primary focus, can create uneven casing loads and weaken the completion at different places.





Cement Void

Poor centralization of the casing can cause drilling fluid voids in the cement, leading to subsequent casing deformation during hydraulic fracturing. This is a particular concern in horizontal wells where the casing will tend to lay on the bottom of the wellbore, which creates eccentricity.

The eccentricity depends on the material weight, applied tension and compression during running, placement of the tubulars and forces around the casing. For eccentric casing, when cement replaces drill-in mud, the chances of leaving behind mud in the upper side between wellbore and casing is high. For a concentric casing, the chance of poor cementing exists but at a reduced scale.

During the cementing phase, if voids occur in the annulus then the drill-in fluids are trapped in these voids. During the fracturing process, the low temperature of the injected fluid can cause contraction of the fluids trapped in the voids thereby putting stress and affecting the cement. This will translate to a change of back pressure on the completion assembly thereby causing it to bend or crack. Poor cementing can also occur if the bedding is naturally fractured. This can cause fluid loss as well as slippage with hydraulic pressure.

Temperature

Thermal change and loading may disrupt normal completion conditions and cause casing failure. The casing will expand and contract at different rates in different sections, depending on the fluids pumped, the variations in surface and bottomhole temperatures, and pressure fluctuation and cycling. If too much temperature contrast occurs, as when cold fluids are pumped into high temperature intervals, the load on the tubulars can be high if they are not properly set and cemented during the completion process.

Erosion

Erosion in a completion assembly can be caused by both mechanical and chemical factors, and must be mitigated to achieve long-term completion integrity and an intervention-free well. The main considerations of a completion system related to erosion are the strength and resistance required to withstand strong pressure and erosional effects due to sand blasting or acid reaction during fracturing processes. Erosion creates weak points in a completion that can fail if high pressure is introduced in that area.

Ballooning

A staged fracturing process in plug-and-perf cemented completions comprises sequential perforation for different stages and subsequent fracturing, causing the pressure to rise and get released inside the casing in cyclic fashion. A good cement behind the pipe secures the completion and does not allow any longitudinal movement of the completion assembly or expansion of the casing.

However, with poor cement bonding, the process of sequential perforation fracturing in multiple stages with cyclic pressure change subjects the assembly to expansion and contraction thereby creating fatigue and weak points. The unequal pressure present at different locations with little or no cement supporting the tubular results in ballooning and pressure changes are accentuated because the other locations are restrained by good cement. Contrasting fracturing fluid and reservoir temperatures can enhance the ballooning effect.

6 Mitigation Strategies for Casing Deformation

Optimal Drilling Practices

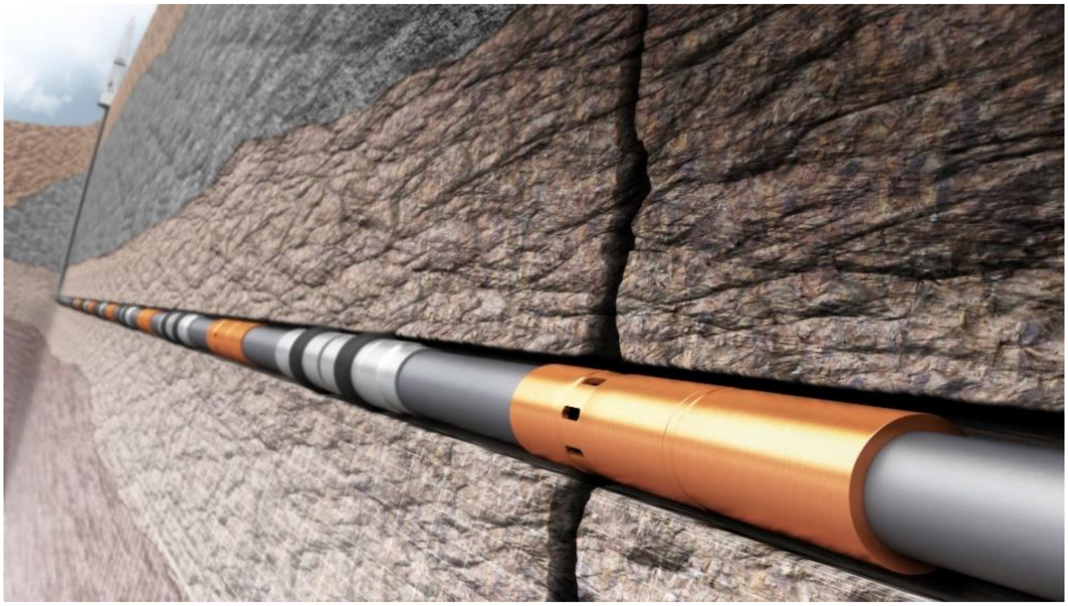
Chemistry of drill-in fluids, borehole trajectory, casing connections, borehole clean up, cementing – should be rigorously designed and implemented. The cement void issue can be mitigated by placing centralizers along the completion string. Proper centralization is essential to keep the completion string concentric to the hole which will dictate the quality of cementing around it. Care should be taken to minimize undulated and contorted wellbores. Rotating the casing string during the cementing process to avoid formation of cement voids or using warm fracturing fluids to minimize the pressure drop inside the voids are potential innovative strategies to solve these difficult problems.

Completion Program

Grade and quality of completion material, equipment and assemblies must be based on formation characteristics and reservoir fluid properties – sweet/sour, pressure, temperature – all factors must be considered during the selection process. Instead of weak and low-grade casings and couplings, high strength casings are required in high stress regimes to comfortably maintain fracturing pressure. Increasing wall thickness is a more effective way to improve the resistance to ovality than increasing steel grade. In addition, reasonable spacing in between frac stages, optimal frac volume in each stage, and improved operational efficiency can also help mitigate casing deformation and failure.

Completion Methodology

Deploying open hole multi-stage completion systems with mechanical packers customized to the formation properties can help mitigate casing deformation. In an operator-led study, fields where open hole completions were used, the number of casing deformation issues reported was close to none. An open hole completion system allows some movement of the casing and avoids poor cement-related problems since the completion is installed with mechanical packers instead of cement. In this system, the pressure inside the casing during fracturing is also outside the tubular, thereby balancing the system and preventing the assembly from ballooning or collapsing.



Hydraulic Fracturing Operation

Production expectation and ultimate recovery should dictate the completion process. While open hole completion assemblies can help mitigate casing deformation, the staged hydraulic fracturing operation must be designed and executed using optimal practices based on formation quality, completion strength and configuration. Proper calculation of formation breakdown pressure is important to ensure that the pressure applied during fracturing stays within the completion range. If for any reason pressure becomes higher and fracture initiation cannot be attained at the desired pressure, remedial measures such as scouring, application of acid, etc., should be applied to further expand fluid entrance and reduce the breakdown pressure.

Best practices during the fracturing process include maintaining treatment pressure under certain thresholds, using optimal fluid volume and proppant mass, using clean fluid and ensuring only slight under-displacement during each stage treatment so as to leave the wellbore essentially clean while maximizing contact of the wellbore with the reservoir through the highly conductive created fracture.

Clean-Up and Production

The best way to clean up is to flow the well back after each fracturing stage is completed so as not to leave the pumped fluid in the formation for a long period of time. However, if logistics and other factors do not allow that and cleaning up of each stage separately causes time delay and additional expense, the well can be cleaned up once all stages are completed.

The clean-up process must follow specified guidelines to maintain completion integrity, as well as fracture conductivity and characteristics. Implementing gradual staged clean-up best practices and procedures is vital to avoid proppant crushing and inducing high stress on completion assembly. Production scheduling should be based upon well and reservoir properties, and estimated ultimate recovery.

Maintenance

Periodic maintenance and monitoring of a well is an essential element for successful operations. Monitoring a well's production over time is an indicator of reservoir and well health. At the beginning of production, pumped fluid should flow back along with the reservoir fluid and the amount of pumped fluid, when measured carefully, can indicate both the reservoir quality and fracturing efficiency.

In tight reservoirs, a large portion of pumped fluid is left behind and can hinder long-term production. When trapped in the induced fracture, leftover pumped fluids deteriorate frac conductivity thereby negatively impacting production performance. Different types of wash fluids and chemicals may be pumped to alter wettability and enhance the release of frac fluids.

During production life, attention must be given to reservoir pressure change and field-wide reservoir pressure monitoring should be conducted to ensure uniform drainage and long-term higher recovery. The most successful way to maintain well production is to ensure uniform pressure depletion by engineered production maintenance strategy in the field. In rare cases when fractures close due to the loss of conductivity, remedial measures can be taken, such as re-fracturing individual wells or waterflooding a reservoir; however, casing deformation issues can hinder attempts to increase production.

FIELD STUDY RESULTS

An operator-led study into casing deformation was conducted across two fields. It was found that in horizontal wells, the casing deformation rate was high in the two fields, which exhibited moderate to tight reservoir quality and wells were completed with plug-and-perf methodology. Statistical analyses show that deformation occurred in 50% of the total hydraulically fractured stages. Based on a complete evaluation of the stages and hydraulic fracturing procedures, it was concluded that the characteristics of drilling and cementing combined with the annular pressure buildup effect in cemented plug-and-perf wells due to pressure imbalances between the outside and inside of the casing during stimulation caused the deformation to occur. There was no indication from the geomechanical analyses that formation slips, displacement, or compaction occurred or contributed to casing deformation.

Failures can be mechanical, exceeding the burst or collapse limit of the tubular, helical buckling, and selection of improper materials. However, all these factors can easily be corrected with proper design and follow up. In the fields and formations that were investigated, the wells that faced casing failures and were analyzed did not have material quality issues, as the quality control and proper selection of materials were robustly carried out.

Many other factors, such as poor cementing and voids, temperature change, magnitude of the injection pressure and in situ stress were investigated and analyzed to evaluate reasons for casing deformation. The results show that in the process of high injection rate hydraulic fracturing, the retention fluid in the cement voids can contract due to a sudden temperature decrease inside the casing. In particular, tight shale reservoirs have an extremely low permeability and cannot supplement the pore pressure by natural flow within a short time. However, all these factors are a consequence of poor cementing.

Also note that high pumping pressure is needed in a high geo-stress formation to initiate and propagate fractures, inducing a higher internal pressure inside the casing. The combined effect of high internal pressure and non-uniform external support, the downhole casing has a high risk of deformation. The cement voids’ pressure decline effect might be the main reason behind the casing deformation in this high geo-stress tight gas play.

Analyses of open hole logs, cement logs and caliper logs in the wells subjected to casing deformation have indicated that the problem did not always occur at or near the perforation. Rather, in many cases, the deformation occurred much higher in the well than the perforated interval, indicating that the high-pressure fluid that exited through the perforation during fracturing did not necessarily contribute to the deformation. In many wells, where the deformation occurred at intervals away from the perforations, the cement logs showed poor cement bonding thereby corroborating the notion that the primary cause of deformation is related to improper placement and poor cementing of the production string.

CONCLUSION

Casing deformation can occur in any phase of a well's lifecycle – completion deployment, stimulation treatment or during production – and is a common problem in cased hole wells with plug-and-perf completions that are hydraulically fractured at high pressure.

The consequences of casing failure can be significant; it can mean a very costly workover procedure if the wellbore becomes inaccessible, bypassing a few producing zones because the stage isolation plugs cannot be drilled out post-treatment, or producing through a deformed wellbore that may leak at different places during the producing life of the well causing hazardous consequences. It can also mean complete abandonment of a well if catastrophic failure occurs above the final fracturing stage, making the wellbore totally inaccessible.

While there are varying causes that can lead to casing deformation, the most common factor identified in an operator-led study in two fields found that cementing issues and voids was the leading cause of casing deformation, which occurred in approximately 50% of all hydraulic fracturing stages of multi-stage horizontal completions.

There are many solutions to help mitigate casing deformation in all phases of a well's lifecycle. The solutions highlighted in this paper include:

1. Optimal Drilling Practices

2. Completion Program
3. Completion Methodology
4. Hydraulic Fracturing Operation
5. Clean-Up and Production
6. Maintenance

Packers Plus is a completion technology company dedicated to providing high quality solutions for a variety of applications, including cemented liner, open hole, high pressure / high temperature (HPHT), multi-lateral and offshore wells. Packers Plus' knowledgeable and experienced specialists have been dedicated to providing customized solutions for clients around the world over 20 years.

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