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Does any aspect of this work flow slow down operations?

These workflows are designed to have no negative impact on operational speed and efficiency. In fact, when a completion is optimized, there is typically a reduction in stage pumping times which can be in the range of 5-20 min/stage. Optimization often leads to lower treating pressures which increases how quickly the maximum pump rate is achieved, while increasing the odds of maintaining that rate. In addition, this style of optimization has been shown to drastically reduce the odds off screenouts which can cause major operational delays.

How does this approach compare to traditional completion methods in terms of efficiency and effectiveness?

Traditional completion methods consist of designing the completion long before the well is drilled, and often before the well is permitted, using a one size fits all approach. During the fracture treatment, minimal changes are made to react to how the well is actually treated. With this workflow operators adapt their completion design based on the well that was actually drilled (Using Drill2Frac's toolbox), while making small adjustments in real-time in regard to how the rock is breaking. This stage by stage customization results in more consistent stage performance, leading to higher EUR's and improved field development.

What are the expected improvements in well performance from using this combined solution?

Clients have realized a number of benefits from the combined solution. In a recent URTeC paper (URTeC 3857017), not only did this combined offering result in a production improvement over offset wells that had not incorporated this solution, but the existing offset producers came back online with minimal production impact. Depending on many factors, including both geological and current completion design, expected production improvements can range from a few percent, to upwards of 25% or more vs non-optimized wells making this one of the highest ROI techniques available on the market. ShearFRAC is providing 2 new measured fracture attributes during fracturing operations to real-time and post stage, which is FSA and PSA. These two attributes can be used to evaluate performance in higher resolution, combining near-wellbore measurements, fracture measurements and production information.

What are all the types of data Corva captures from Drill2Frac and ShearFRAC?

The technology space of real-time big data analytics is evolving rapidly. We continue to add new features after robust beta testing to ensure these metrics offer value rather than “Dashboard Clutter”. Currently Corva captures two new measured fracture attributes from ShearFRAC during fracturing operations:

Fractured Surface Area (FSA) and Productive Surface Area (PSA). These attributes have been calculated and validated across hundreds of stages and are further cross referenced against calculated pressure and rate transient analysis measurements. This coupled with Drill2Frac's measurements at the bit of Action Fractures allows for a higher resolution performance evaluation when combined and in real time.

For MSE calculations, do we need bottom hole measurements, as transforming surface data is highly complex without knowledge of friction factors and contact points?

For the last 10 years, Drill2Frac has been creating RockMSE® using only surface measurements with incredibly accurate results in hundreds of wells every year. The process includes a vast number of corrections to account for the highly complex drilling process which is where our strength comes in. While a downhole measurement of WOB and Torque can be incorporated in our workflow and would allow for somewhat higher resolution and higher accuracy in areas such as slides, the additional expense and operational risk is typically not warranted.

Would you advise moving frac clusters based on this workflow?

The first step in optimizing completions using this workflow is determining the optimal completion design for the specific rock properties which is done through our FlowFX™ near-wellbore fluid distribution simulator. The next level of optimization comes from placing stages in such a way that the number of stages that straddle different rock types is minimized. The final step can include placing clusters in optimal locations such as having them in similar rock, and includes placing them in a way that they avoid areas of localized depletion.

I would love to hear your thoughts on perf erosion's impact on cluster efficiency? Also, once initiated the frac will be dictated by far field stresses, how this is incorporated?

Perf erosion is a major factor in fluid distribution among clusters along with the completion design, near wellbore rock properties, stress shadowing (both inter-stage and intra-stage) and dynamic flow behaviors, all of which is taken into account with Drill2Frac's FlowFX. While far field geomechanics will greatly impact fracture growth such as length, height and width, the assumption FlowFX makes is that those far-field properties will be consistent between all clusters, and in most cases will have minimal impact on uniformity index.

In terms of automation, what changes can be made in real time using AI? What kind of timeline is the industry looking at for this to be implemented?

In terms of automation, AI will facilitate both proactive and reactive changes. Proactively, it allows for adjustments in wellbore architecture, and the completion design, stage length, perforation design and planned proppant and fluid bases. Reactively, AI will automate modifications to parameters like rate, proppant concentration, and chemical injections. The future of automation in the completions industry includes real-time changes to these parameters during stimulation operations without human intervention. Corva, along with Drill2Frac and ShearFRAC are taking the necessary steps to facilitate this automation from a technology standpoint however, this level of automation requires significant collaboration within the industry and the timeline for full implementation is dependent on the pooling of additional resources from various industry partners.

When optimizing stages in the Drill2Frac workflow, what are typical adjustments to stage lengths to account for rock heterogeneity?

As a baseline, we normally start with a customer's existing design, and the adjustments made depend on each individual client's objectives and philosophies. If the goal is to keep stages within specific rock types, individual stage lengths may need to be adjusted by +/- 10-25%. In addition, for a fully optimized completion, operators may choose to adjust stage lengths based on the level of heterogeneity within a stage as it is easier to get higher UI's in low heterogeneity stages. Thus, similar UI's could be obtained in low heterogeneity stages with longer stage lengths, and more clusters vs stages with higher heterogeneity.

With FDI mitigation do you need to skip a stage or reduce the number of perforations or number of clusters to minimize pressure responses in the offsetting wells.

Typically, we do not recommend skipping stages, and often perforation clusters can be placed around areas of localized depletion without reducing the number of clusters. However, depending on each operator's risk tolerance, the actual method of mitigation will vary. Looking to the future, automation can be used to make changes in rate, proppant and chemical concentrations in real time during stimulation operations. These changes and implementations require significant collaboration within industry and the timeline for this is dependent on the combination of resources from varying industry partners.

How does the machine learning algorithm work during fracturing operations?

The machine learning algorithm is best described as a Human-Assisted Deep Learning Algorithm. This has been built and validated against a vast data pool encompassing all commercial basins and benches across North America through our shared learning partnership between Corva, Drill2Frac and ShearFRAC. With simultaneous operations, the algorithm will continue to optimize itself with learnings from each stage, removing the impact of human experience biases with Corva data aggregation and ultimately enabling every Completions Engineer to optimize both current and future stages with easy visualizations which encompass all aggregated past learnings. By maintaining a clean data lake architecture within the partnership we believe it has the ability to bring value across the entire development life, from your current operations, to parent wells impact mitigation and ultimately full field development planning. We believe this marks a significant advancement in the energy sector by applying the latest refinements in large data set machine learning algorithms to increase the current NPV of any development and assist in mitigating value erosion.

I've seen performance damage to child and parent wells due to child well completions being under-designed. How often does this workflow end up decreasing the job size i.e. total sand due to parent child interactions?

This workflow typically does not impact baseline job sizes, but is focused around taking an existing design and adapting it to the actual well that was drilled. As such, we will not typically reduce job sizes. However, in some cases, without mitigation, some operators may be reducing job size with the goal of minimizing fracture interactions. Using the workflow outlined, we incorporate methods both in the pre-job planning, and during execution to mitigate fracture interactions, which might then allow for larger job designs. To address concerns about under-designed completions in child wells, the collaborative approach involves using the proactive Drill2Frac's Rock Mechanics Specific Energy (MSE) calculations and the reactive ShearFRAC's real-time measurements. Proactive planning leads to more impactful reactive measures to mitigate the parent-child interactions while optimizing fractured surface area and maintaining planned proppant volumes. Proactively, areas of depletion are highlighted from the RockMSE data and integrated into a real-time data-driven Fracture Driven Interaction (FDI) mitigation workflow along with high-resolution offset pressure monitoring and the ShearFRAC measurements. The reactive FDI mitigation uses sand slugs or diverters, along with an initial rate drop, to effectively manage "runaway" fractures, diverting the fracture tip from the parent well. Refocusing the stimulation energy into the surrounding rock of the child well is confirmed by ShearFRAC fracture frequency and fractured surface area measurements. Once the fracture tip is under control, the fracture operations will be typically run at the original planned rate and tonnage.

This data driven workflow is facilitated through the Corva partnership by ensuring the aforementioned measurements and pertinent frac KPIs are easily accessible on a single dashboard. Job size reductions are reserved for very rare situations where the "runaway" fractures are unable to be controlled when the parent well's production and integrity is in jeopardy.

How can the incorporation of real-time monitoring and sensor technologies contribute to the optimization of fracture management in critical structures, and what challenges need to be addressed for their widespread implementation?

The incorporation of real-time monitoring and sensor technologies, like those provided by ShearFRAC, are a key element in understanding the influence of rock heterogeneity in the subsurface environment which is crucial to optimizing fracture management. These technologies offer real-time insights into fracture area and density, shedding light on how the rock is fracturing subsurface. As fracture attributes evolve, they reveal changes in rock heterogeneity and subsurface conditions, which are pivotal for making informed operational decisions. The widespread implementation of these technologies faces challenges, including integration with existing systems and ensuring data accuracy and reliability. Our 3 companies aim to address these challenges through collaboration, facilitating the integration of systems along with the acquisition of high quality, unfiltered data.

Besides production data, what other diagnostic tools have been used to evaluate the effectiveness of the engineered design recommended by Drill2frac depletion identification workflows?

Drill2Frac's process of locating localized depletion has been validated using virtually all of the standard diagnostics available in the industry including: fiber optics, microseismic, tracers, resistivity image logs, pumping pressures, etc. Similarly, the impact of designing a completion to avoid these areas of depletion have been validated, not only by increasing production on the child well, but also significantly less damage to offset wells. Also, clients have experienced significant increases in volumes to first response when monitoring offset parent wells.

What wells (formations) were impacted the most by offset fracing?

In our experience, the presence of depleted fractures has been seen in all unconventional basins that we have worked in. The impact of offset fracing can definitely vary among basins and can include significant production degradation, sanding out of laterals and even production improvement. However, it should be noted that many experts agree that production improvement in offset wells is often the result of a pathway being created between the depleted parent well and the newly completed infill. Thus the "production improvement" seen may actually be a parasitic draw from the newly completed infill. Regardless of the impact on the parent well, optimizing completions to minimize these interactions results in better stimulation of the treatment well as the fluid pumped is not being lost to offset producers. The key learnings from these in-situ scaled injection tests on actual reservoir rock demonstrates the significance of a reservoir's internal rock fabric and bedding planes on the resultant fracture geometry, regardless of stress orientation. This sample was tested in both strike-slip and normal orientations across 12 total experiments as the initial output geometries would not behave as the textbook suggested, so a full spectrum of principal stresses was applied over 12 experiments on 12 separate samples. Ultimately the 1D MEM is believed to be correct and tested sample opening against Sigma 2 is mathematically validated in FDEM modeling due to variable tensile strength or cohesion if the bedding planes themselves. This is worth noting as all commercial fracture modeling software does not have the ability to model anisotropy or a dual system tensile strength model. However, bench tested concepts and images suggestive of bedding plane parting are additionally supported in our experience across various basins and target formations.

Have you run production diagnostics (PLT, chemical tracers, fiber optics flow measurement) to compare operational decisions to well performance?

Yes, production diagnostics like PLT, chemical tracers, and fiber optics flow measurement have been conducted on wells that have concurrent ShearFRAC measurements. These diagnostics have a strong correlation with ShearFRAC measurements during both the fracture treatment and post-completion production analysis. The three independent area measurement outputs – fractured surface area, producing surface area, and flowing surface area – provide deeper insights into fracture and production performance. The fractured and producing area measurements correlate with production and provide additional key insights not only to the current well being treated, but also offers learnings with respect to offset depletion and well spacing to mitigate overcapitalization. One point to note is that the above-mentioned diagnostics (PLT, Tracers, and DAS) are all postmortem evaluation tools with the analysis completed after stimulation and flowback. ShearFRAC's diagnostic tools are the only productivity indicator tool available to industry in real time. This empowers our partners to make data-driven decisions related to the fine-tuning of rate, proppant, and chemical concentrations during operations based on the reaction from the reservoir. In addition, real-time measurements enable quick iteration of revised frac schedules and other technology experimentation as months of production are no longer required for evaluation of adjusted pumping metrics, ultimately increasing NPV of assets faster.

How does this improvement benefit FLOWBACK operations?

Drill2Frac's measurements of depleted fracture networks along with the fracture performance and reservoir attributes obtained by ShearFRAC can provide benefits to post-completion flowback operations by identifying areas within the wellbore that may be problematic. Identification of areas such as under pressured zones, areas with formation damage or additional connectivity to faults or lineaments that may influence operations such as milling or cleanouts aids in enhancing efficiency thereby mitigating costly remediation operations. By acquiring this information on a stage level basis coupled with being benchmarked against numerous production values, we can be proactive during flowback operations with deeper insights into potential problematic areas along the lateral. We aim to evaluate stage-level post-frac production performance immediately after stimulation, rather than relying solely on standard 90-day production analysis, providing another layer of insightful information to be applied during post-completion operations including but not limited to flowback operations.

Related to the laboratory studies we notice the true triaxial test ... what about the test results from the DSCA (Differential strain curve analysis)?

DSCA was a technique introduced in 1983 by Ren and Roegiers to establish in-situ stress state from core. A novel technique in its time, DSCA introduces further uncertainty as this correlation is rooted in a linear correlation for the generation of randomly oriented microcracks with an inferred density which is proportional to the stress magnitude differential. This process requires careful monitoring of a rock specimen's behavior upon reloading to determine the past stress history.

In the series of true triaxial testing, the Montney formation which the experiment was conducted on has a very complex burial, multi-phased catagenic generation of hydrocarbons and various proposed times of uplift, syn, post and pre tectonic deformation. 1D and 3D mechanical earth models were validated against proven field measurements on a population of over 1100 wells and ~7Kms of full diameter core. Careful attention was paid to the second order crenulation fabric observed on core surfaces to orient the core in the poly-axial system to capture the Laramide orogeny micro-finger printing on the rock fabric. These parameters were clearly set with the least principal stress vector on the same plane but perpendicular to sigma one. While sigma two in the test vessel was oriented perpendicular to both previously mentioned vectors as an overburden stress.

For this reason, both technical teams would like to bring attention back to the key takeaways from the experimental tests while also acknowledging the validity of the question. However, by varying principal stress vectors from strike slip to normal regimes we do believe that all errors which may be possible in the generation of field derived mechanical earth models have been captured in the data presented.

The key takeaway of these tests is that all of the blocks tested under a spectrum of principal stress magnitudes yielded the same outcome with 70 -90% of the SRV generated via the opening of bedding planes and against sigma two. The mechanism of this preferential failure was mathematically validated by testing both perpendicular and parallel to bedding orientation, yielding a difference of ~10 Mpa due to lower strength cohesion related to bedding plane opening.``

What are your findings on RockMSE's mechanical properties combined with cutting's?

There is no doubt that incorporating cuttings with RockMSE can improve the overall understanding of rock properties. That is why, when available, we include cuttings analysis on our OmniLog, allowing customers to visualize how changes in cuttings impact RockMSE. Overall, the technical and research divisions acknowledge the validity of this question, and it will be something we assess and correlate to its validity against field measurements. The team also doesn't want to discount the significance of the outcome of the test results with an established and controlled set of input parameters. These parameters were clearly set with the least principal stress vector on the same plane but perpendicular to sigma one. While sigma two in the test vessel was oriented perpendicular to both previously mentioned vectors as an overburden stress. The key takeaway of these tests is that all of the blocks tested under a spectrum of principal stress magnitudes all yielded the same outcome with 70 -90% of the SRV generated via the opening of bedding planes and against sigma two. The mechanism of this preferential failure was mathematically validated by testing both perpendicular and parallel to bedding orientation, yielding a difference of ~10 Mpa due to lower strength cohesion related to bedding plane opening. For this reason, both technical teams would like to bring attention back to the key takeaways from the experimental tests while also acknowledging the validity of the question. However, by varying principal stress vectors from strike slip to normal regimes we do believe that all errors which may be possible in the generation of field derived mechanical earth models have been captured in the data presented.

In order to characterize the fracture what about using PIWD (Production Index While Drilling) especially when we are drilling in MPD (Managed Pressure While Drilling)

Managed Pressure While Drilling (MPD) is an effective way to control losses and establish well control in complex and varied pore pressure systems. However, due to its cost of implementation, it has not become a practice that has been universally adopted in the industry. MPD is typically reserved for wildcat exploration and basin specific applications as a cost avoidance measure to increase ROP in super-over pressured reservoirs and to potentially avoid the use of additional casing strings within the wellbore.

Both Drill2Frac and ShearFRAC have come up with optimization strategies based on data that can be collected on any and every multi-stage development project. By collecting, analyzing and training robust data sets through the use of multi-layered machine learning we are able to implement learnings from basins globally into each hydraulically fractured well offering unique optimization opportunities at a marginal cost, when considered against the proposed alternative of MPD or PIWD.

For real-time design changes and automation, do you think there is more benefit to the child wells or parent wells?

Real-time design changes and automation has shown benefits in both parent and child wells. For parent wells, these real-time fracture measurements provide additional data points that increase decision-making confidence in completion operations, including proppant concentration and fluid viscosity. In child wells, the ability to incorporate offset monitoring into the FracBRAIN® real-time platform offers an additional layer of understanding to the spatiality of the fracture network creation, including frac hit avoidance which may negatively impact producing wells and booked reserves. This spatiality component allows for the ability to estimate fracture half lengths and the ability to evaluate cluster efficiency. The industry tends to favor offset monitoring for its clarity and tangible benefits but unlike in child wells, such data is not readily available for parent wells. By digesting the EDR data of both child and parent wells through Drill2Frac, we take a proactive and prescriptive approach.

How do you react proactively to signs of screen-out in real time?

Drill2Frac uses data collected during drilling operations to calculate mechanical strength estimates along the lateral (RockMSE). This is a key prescriptive analytical metric allowing us to identify heterogeneity and variable facies anisotropy along the lateral prior to the commencement of completion operations. Collaboration across our multidiscipline technical teams' assess the properties of each stage to assess risk and reduce the possibility of screen-outs during stimulation operations. By preemptively flagging areas of concern prior to completion, we are given the opportunity to provide a more prescriptive approach when completing these stages.

This information, coupled with ShearFRAC's real-time measurement of fracture frequency, can indicate the early signs of a screen-out through an observed frequency reduction in fracture activity. This paired approach of flagging potential risks and early time warning flags is a valuable tool for field operations where adjustments can be made to alter proppant transport with small modifications to rate, proppant concentration, and fluid viscosity. These adjustments are prioritized based on the rock type identified in the current stage as well as active pumping conditions, however we believe this integrative approach provides intrinsic value offering discussion to happen prior to moving on location and as a proven early warning system to engage the mitigation technique to avoid the screen out.

The Corva platform provides the bridge between the E&P partner's fracturing operations team onsite and real-time operating center, Drill2Frac and ShearFrac facilitating the necessary data cooperation to be both proactive and reactive.

What would you do differently in places where success was less than expected?

Drawing from the wellbore measurements as well as a large set of experiences, the odds of improvement are greatly improved, however, there are still many unknowns, thus there can be times when results are not as expected. The strength of this workflow however is that it is data driven. The combination of wellbore data obtained from Drill2Frac, pumping diagnostics from ShearFRAC, and a group of highly experienced experts, provides the means to analyze the outcome and attempt to determine what changes can be made going forward. With this feedback loop, we can ensure continual improvement.