Sustainable Sand Management Control and Solutions - Balancing Performance, Costs, and Environment

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Application of improved gravel packing techniques to reduce mechanical skin in Internal gravel packs in a matured asset

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Background

- BSP has a long history of gravel pack completions dominated initially by internal gravel packs but with increasing share of OHGP's over the last two decades as the technology matured
- IGP's continue to be a popular completion choice for BSP with more than 25% of new wells still completed as IGP's (includes *HRWP's and frac packs*)
    - Thin Oil rims development
    - Gas cap isolation
    - Significant water intervals in between sands
    - High perm streaks avoidance etc
- Initial mechanical skin values reported for IGP's for BSP's historical gravel packs vary from 25-50. Over time, this has been seen to reach >50 in almost all cases with long term forecasting using a value of 50-90 for IGP completions
- In most cases, packing factors usually 1-20 ppf were targeted
- Over the last few years, BSP has implemented several improvements in the way Internal gravel packs (IGP's) are executed - the focus of these improvements was both productivity improvements in the production lifecycle as well as better execution.
- To confirm if these changes have improved the productivity of these wells, PTA (Pressure transient analysis) based skin analysis was done on several such wells during the first 3 months of their production
- Idea was that if improvements are seen, these would be replicated across BSP

PTA introduction

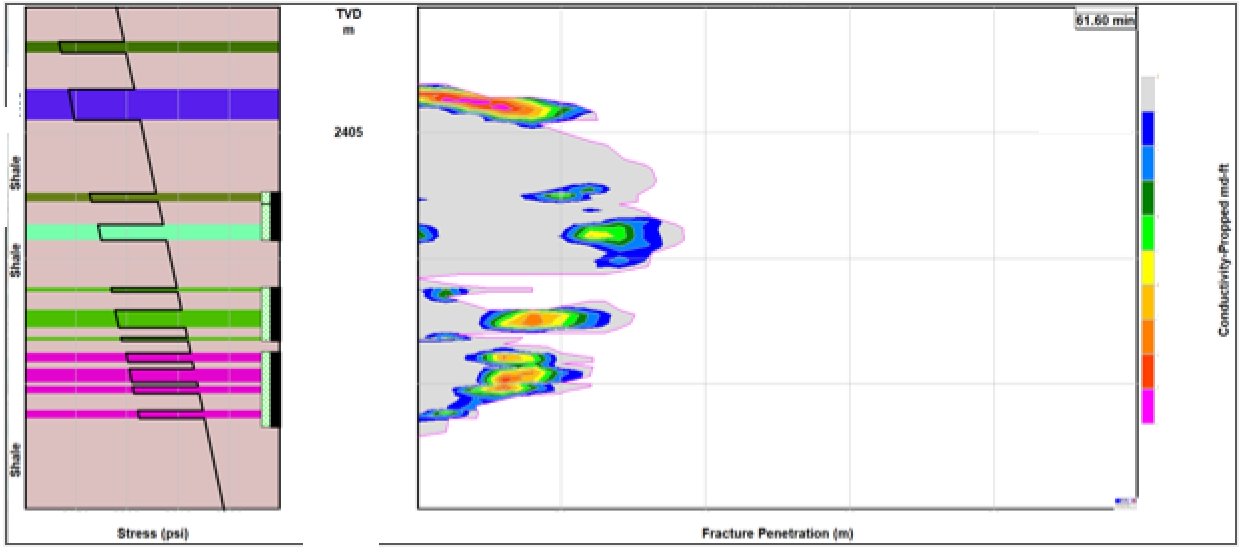
- Pressure transient analysis of a well is considered the gold standard for understanding mechanical skin in the well completion reservoir interface
- It is relatively independent of kH uncertainties unlike a well model where skin analysis using rate matching relies on kH accuracy
- Also separates mechanical skin from rate dependent skin
- Meaningful to do this through well's lifecycle to understand skin development over time and identify stimulation opportunities
- Doing it early in life helps understand damage mechanism and lowest achievable skin from the completion

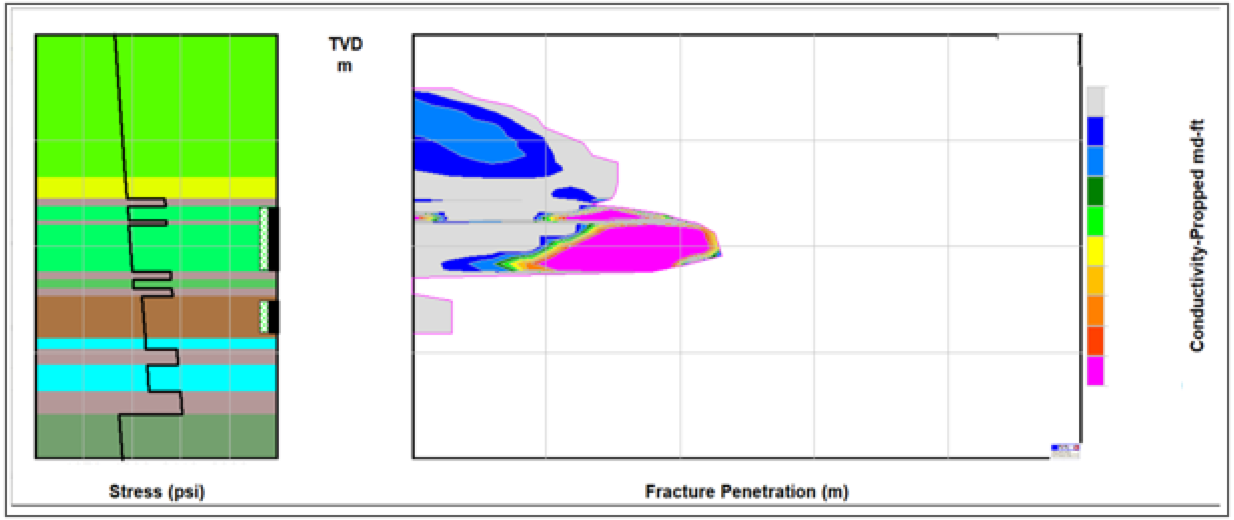
IGP execution old methodology

- Most of the BSP IGP's historically were executed as circulation packs with fear of fracture growth reaching unintended zones (water/gas/high/low pressure zones)
- No modelling of fracture growth was done and a general 'fear' of fraccing drove the IGP completions to be mostly circulation packs
- After years of such practices being implemented, execution teams were reluctant to go above fracture pressure with uncontrolled losses, breaking into unintended formations etc often cited as reasons
- Acidization wasn't used in most jobs pre 2019 and when used, the treatment volumes had no standardization and often relied only on vendor input with little oversight. Also, choice of acid used varied across fields and vendors with no standardization
- If gas/water contacts were seen (oil wells), acidization volumes were reduced significantly (*as low as 5 gal/ft*) without verification using a simulation software to see what's safe and what isn't
- Average lowest initial mechanical skin observed in wells with no acidization and no fraccing was >50 and with non optimized acidization but no fraccing was 25
- No PDHG's used in most IGP wells – PTA couldn't be done without an intervention

Improvements implemented – fraccing

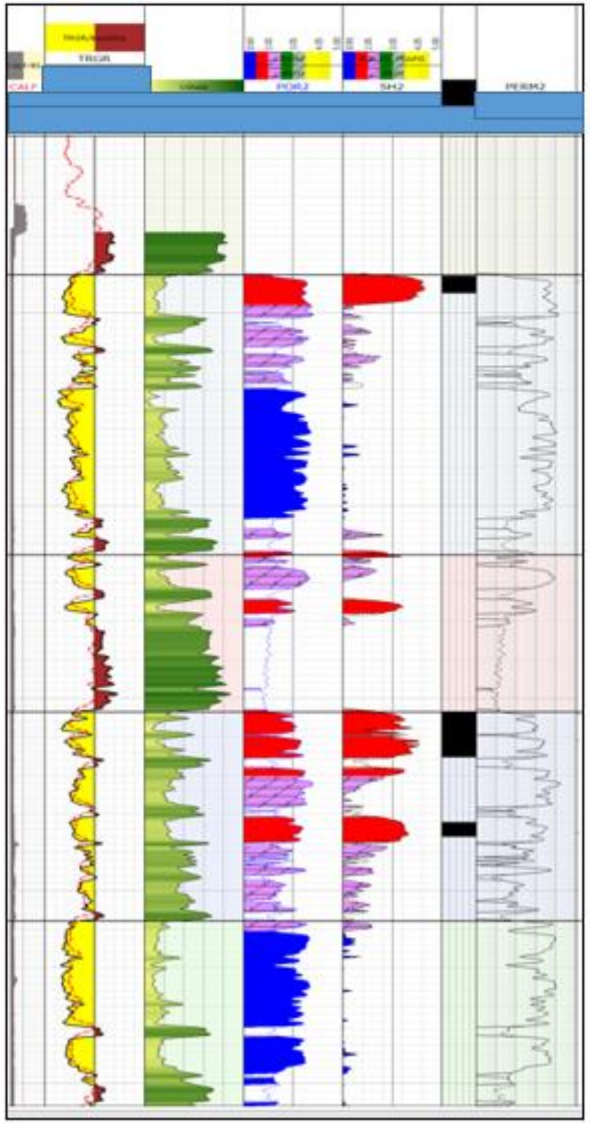
- Mindset change required general education across the organization that fracture growth can be predicted reasonably well in the fields here due to large formation data availability after decades of drilling information from these reservoirs
- Several fracture growth softwares were evaluated and 'Software X' was selected due to ease of usage and ability to model required uncertainties with sufficient details.
- Slide shows example of such simulations being run for a proposed extension gravel pack where gravel is pumped at higher than frac pressures
- As can be seen, the shallowest frac doesn't grow into the water layer

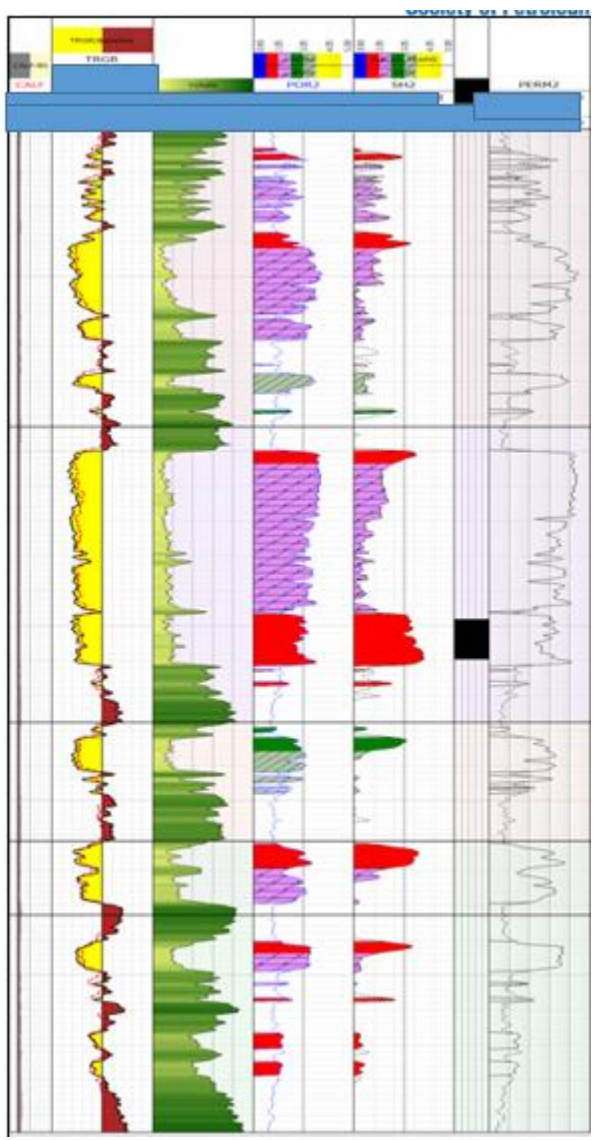




Fraccing observations

- The example shown here shows the complexity of designing fraccing for this well with several gas/water layers seen in the well
- In zone 1 , for example all fraccing scenarios showed growth into water zone – hence only acidization optimizations were made
- In zone 2,3 though, the frac growth could be controlled with an optimized rate vs pressure strategy and this was implemented
- For over one year, all three zones have produced water free (confirmed with MPLT) – several other examples like this



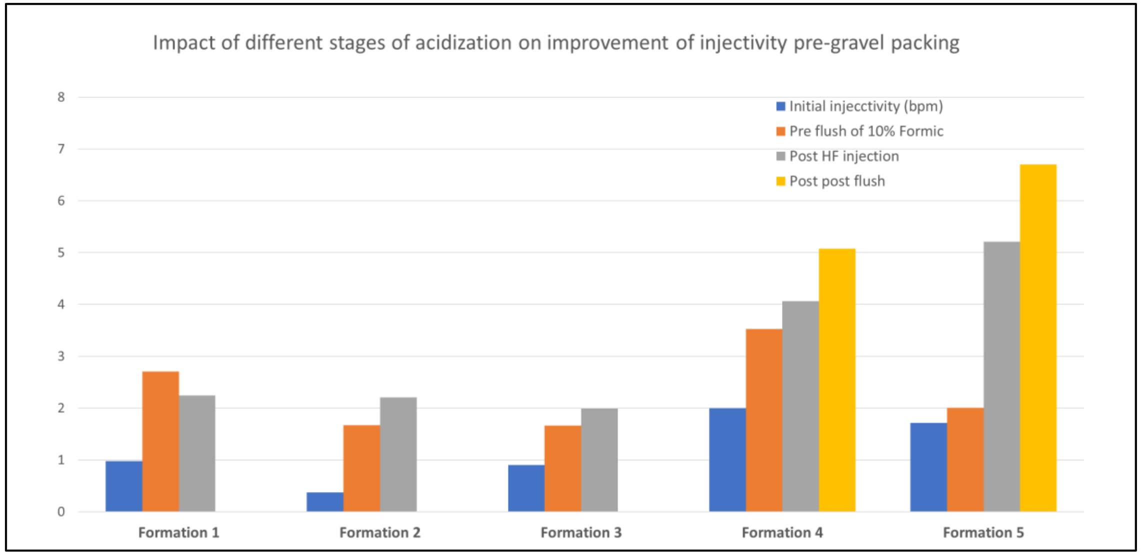


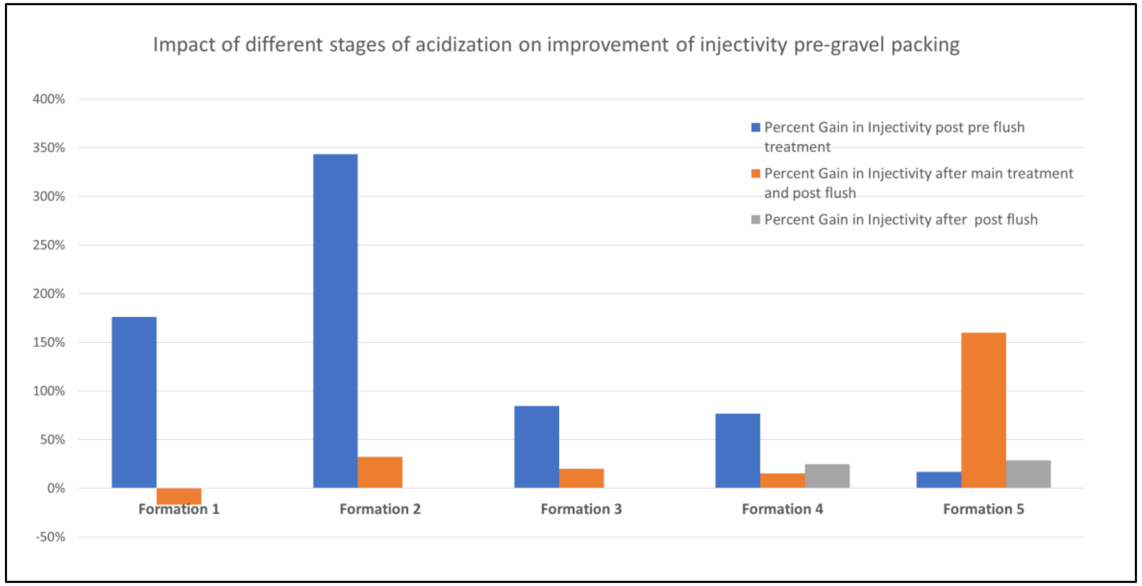
Improvements implemented – acidization

- Based on global Shell benchmarks, acidization was made as mandatory for all IGP jobs
- Acidization was standardized into two groups of wells – based on temperatures at reservoir level and formation fines content
- For high temperature and/or high fines fields, a 75-100 gal/ft treatment technique of pre flush/formic-HF (10:1)/post flush was implemented
- For normal temperature/ low fines content fields, a 75-100 gal/ft 9:1 mud acid treatment was standardized
- For cases in which contacts were close by, stimulation software was used to simulate if the acid volume would go significantly into the water/gas leg of the reservoir – accordingly acidization volumes were modified
- Use of diverters only if formation has significant perm contrast and one diverter stage only for net intervals more than 15 - 20 m
- It was also observed that the largest gain in injectivity comes from pre flush acid (organic or HCl) and hence if for some reason, HF couldn't be used, relatively minor loss of injectivity is to expected. This isn't true for all fields in BSP though. BSP therefore maintains use of HF in all IGP executions except for single trip shunted IGP completions where HF isn't used for risk of inability to control its injection into different formations
- Often acidization scope takes significant time out of the total gravel packing job timing – however the achieved packing factors and skin values have shown that this is economically quite attractive due to high return on investment

Which acid stage helps improve productivity most?

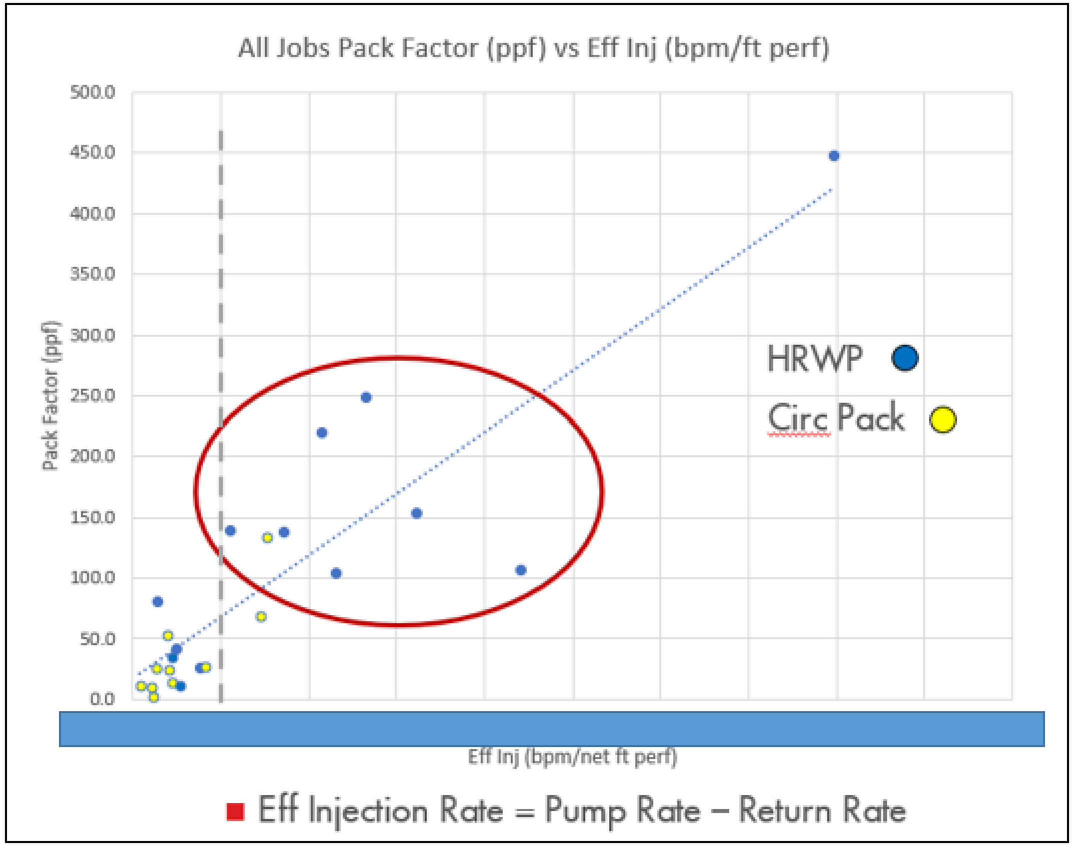
- IGP's are treated with a 5-stage design normally with HCl/organic acid as first stage followed by organic/HCL-HF stages
- Results show that the biggest impact of improvement in injectivity comes from pre flush treatments (HCl/formic) in 4/5 cases
- This is contrary to expectation that HF is more important
- Likely explanation for this is that most of the damage due to perforations/drilling can be removed by a strong non HF acid – while fines removal is also essential, the improvement of initial injectivity is driven by filter cake and perforation debris removal which can be done with a pre flush acid
- It should be noted that with one exception, HF did improve injectivity in all cases
- Consistent answer seen in 20 cases





Extension pack packing factors vs net perf length

- As expected, packing factors in Extension packs/HRWP tend to reduce with increase in net length
- Effective Injection has a large impact on Pack Factor
- Pack Factor > 100 ppf has been seen when Eff Inj is > xx bpm/net ft perf.
  - This is now recommended for designing all IGP jobs
- However, in reality, initial skin isn't governed by packing factors – but more by acidization performance and fracture length extension
- Long term though, this is likely to impact skin as fines move through perforation tunnels and plug them up
- Depending upon initial skin, ramp ups need to be done slowly/extra slowly to prevent skin increase



Improvements implemented – controlled bean up

- A more controlled bean up of all IGP completions was also implemented
- Earlier mindset was that since a sand control is available, there is no drawdown limit per se
- A strict rates or/and drawdown-based ramp up strategy was implemented
- Maintaining a downhole gauge in every IGP well has been made a standard – the ramp up strategy incorporates small drawdown steps towards peak target rate rather than oil/gas rate steps
- Checks on downhole velocities are also done using a standardized tool – this is to ensure that annular velocities are kept within limits considered ‘safe’

Mechanical Skin Results

- These changes were implemented in a phased approach with initial focus on fraccing initiatives in 2019-2020 and acidization improvements implemented in all IGP's executed post 2020
- Overall initial skin values post implementation are 1/3rd or lower than that of what used to be before
- High packing factors expected to help keep skin values lower over a longer period of time
- Well A well below didn't have these changes and it can be seen that its skin is significantly higher
- Well E achieved a record negative skin of -1.5 which is the target for Extension packs

Well	Well type	PTA based Mechanical skin	Comments
Well A	Circulation/Extension pack	21	Packing factor 79 lb/ppf calculated analytically (could be different in reality*); no fracturing; no acidization; High injectivity post perforation (massive losses)
Well B	Extension pack	9	Packing factor 25 ppf; fracturing done, HCl:HF acidization.
Well C	Extension pack	10	Packing factor 220 ppf; fracturing done, HCl:HF acidization.
Well D	Extension pack	4	Packing factor 50 ppf; fracturing done, HCl:HF acidization.
Well E	Extension pack	-1.5	Packing factor 35 ppf; fracturing done, Formic:HF acidization

Conclusion

- BSP's productivity improvement journey in gravel pack is described
- Huge improvements in IGP initial skin have been made with acidization and fracturing - All IGP wells brought online using the highlighted methods show production rates significantly higher at the planned drawdown which validates the low skin seen on these wells
- Acidization and ramp up improvements have nevertheless helped achieve lower initial skin values in IGP wells - regular PTA analysis is recommended to confirm is skin is increasing which can then be remediated in WRFM lifecycle using stimulation techniques
- A variety of tools were implemented in execution phase to achieve this –
  - Breaker placement and losses mitigation techniques
  - Fraccing of formations whenever feasible
  - Acidization design strategy and optimizations
  - Understanding of pumping rates vs net perf lengths
  - Use of PDHG's to conduct PTA and close the loop with front end design of new PTA's – maintain database of critical parameters of IGP's over the years