Using the revised and improved API19B to enhance your perforating performance

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Disclaimer

- This presentation is not on behalf of the API and may not represent the API.
- As a member of the API RP 19b committee since 2006 and Chairman since 2010, I have been instrumental in pushing forwards the improvements and changes to the Standard.

Acknowledgements

- Voluntary efforts by numerous engineers working for Operators, Service Companies and Manufacturers make it possible to have well thought thru and high quality API Standards. It is their efforts which make it possible for you to have access to these important standards.
- Think how you can help deliver standards, with the API or other standards organizations and most importantly volunteer with the SPE.
- I would like to thank the SPE for this opportunity to present on perforating, a discipline which is key to well performance and is often neglected for lack of understanding of the complexities.
- Thanks to Brenden Grove for kindly volunteering to Moderate for me.

Acknowledgements

- Some of our API SC19b committee at a meeting in 2018.

API Perforating Committees Explanation

- There are now 3 API committees involved with perforating.
- API RP 19b Recommended Practices for Evaluation of Well Perforators
  - To be covered in this presentation.
- API RP 67 Recommended Practice for Oilfield Explosives Safety
  - Covers all aspects of explosives safety.
  - The new edition comes with a major increase in scope and is much more comprehensive and detailed.

API Perforating Committees Explanation

- There are now 3 API committees involved with perforating.
- API RP 19SC Specification for Downhole Perforating Tools and related Equipment cont.
  - This is a newly formed RP committee created due to some ongoing issues with Perforating Tools.
  - Defines a minimum standard for reporting and validating operational ratings of perforating tools that are currently not addressed by existing standards.
  - Includes Perforating guns and materials, Threaded connections and seals, Energetic cutters and pipe recover tools and Tandem subs / Crossovers.

Poll Question

What aspects of perforating are you mostly involved with?

Poll Question

Do you use API RP 19b or API RP 67 in your work?

Poll Question

Do you think understanding and measuring the actual performance of perforators is important for your work?

Agenda

- Introduction
- Measuring Perforator Performance
- Recognizing the importance of measuring performance in simulated downhole conditions – Downhole Perforator Performance
- Review of the new RP 19B.
- Conclusion and Takeaways

Introduction

- The old benchmark for indicating perforation performance in the well was a surface gun test into concrete. However, it became recognized that shooting an API concrete target at a surface could not be effectively correlated with actual downhole conditions of overburden, reservoir pressure and rock properties.
- Operators were working in more complex and difficult reservoir conditions and needed to know how to select charges based on how they might work in their wells. Some Operators even worked with contractors to design charges specifically for their own more difficult fields.
- Having carefully designed their charges to work well in concrete at surface, service contractors and manufacturers were finally persuaded to accept that attempting to correlate real well conditions with concrete was not helpful to the Operators and their well performance.

Introduction

- After years of effort by a large team of volunteers, new standards have now been written to promote shots into stressed rock targets, as the standard for identifying performance down hole.
- All the major contractors and manufacturers now have dedicated facilities to provide stressed rock tests and are actively developing improved charges that work well in real reservoir conditions, rather than concrete at surface.
- Having passed through over a decade with almost no new developments in perforating, the last 5 years have seen significant developments in technology, with contractors and manufacturers working actively to improve performance and technology.

Introduction

- What we were told when API RP 19B was introduced in November 2000 and a Section 1. 16/30 Frac Sand and Cement target was proposed.
- Why API penetration is measured in concrete and not rock?
  - Rock is the best target but is expensive and not repeatable
  - Concrete is a repeatable target and reasonable cost
  - Large database of performance in concrete
- So - convenient for the Contractor, but not at all helpful to the Operator who wants the best charge for downhole conditions.

Measuring Perforator Performance

- For most wells, perforating is the only connection to the reservoir.
- Getting this right is essential to well performance.
- But what witnessed data was available for all charges?
- Only API RP Sect 1 concrete performance available to compare charges.
- But....

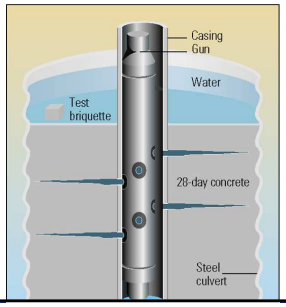
"Penetration Data recorded in API RP19B Section 1 may not directly correlate to penetration downhole".

- Inserted into API RP 19B while under revision.

Measuring Perforator Performance

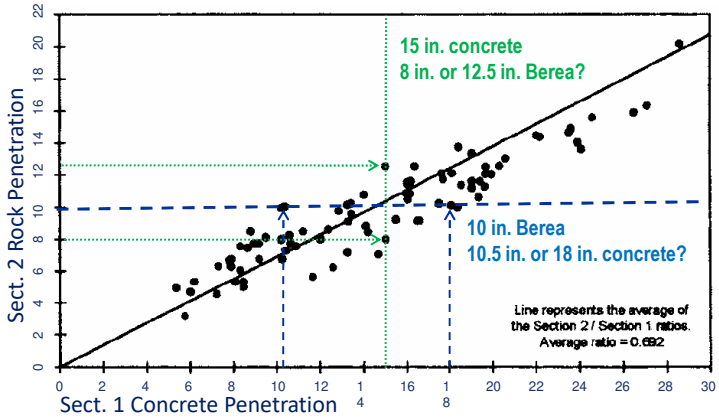
Section 1

- Perforator performance has been measured using API RP 19B Sect. 1
  - Both charge and gun performance were measured using Section 1. A section of loaded gun is shot in water inside a carefully specified concrete target under atmospheric conditions.
  - Section 1 does provide a good overall indicator of charge to charge interference in the gun and an indicative range of perforator penetration
  - Does not provide any useful measure of rock penetration



Measuring Perforator Performance

Sect. 1 concrete data correlation to Sect. 2 rock penetration

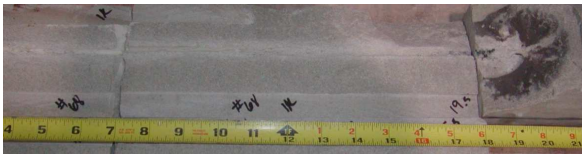


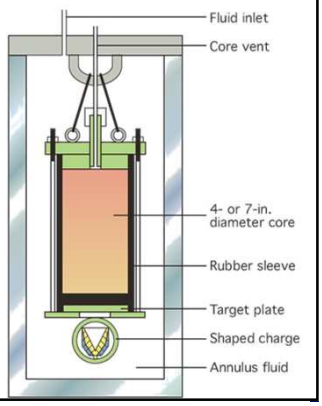
This is old published data and has been known for years.

Measuring Perforator Performance

Section 2

- Single shot into a stressed Berea sandstone
  - Section 2 is useful for indicating relative performance of charges in stressed rock.
  - Is also used as a charge development tool using other target rocks.
  - Although limited, this is far more useful as a reference for selecting charges.

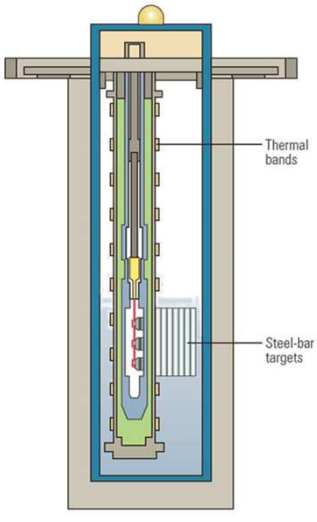




Measuring Perforator Performance

Section 3

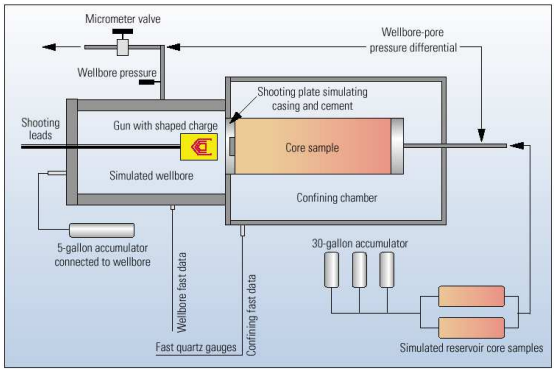
- Single shot into a steel target under temperature
  - Section 3 provides a reference performance for charges shot at temperature.
  - Charges behave differently at higher temperatures.



Measuring Perforator Performance

Section 4

- Single shot into a stressed rock target with fluid pressure and flow
  - Section 4 is shot with simulated gun volume, well bore and reservoir pressure.
  - Closest thing to simulating downhole conditions.
  - Can also simulate flow thru a perforating



Measuring Perforator Performance

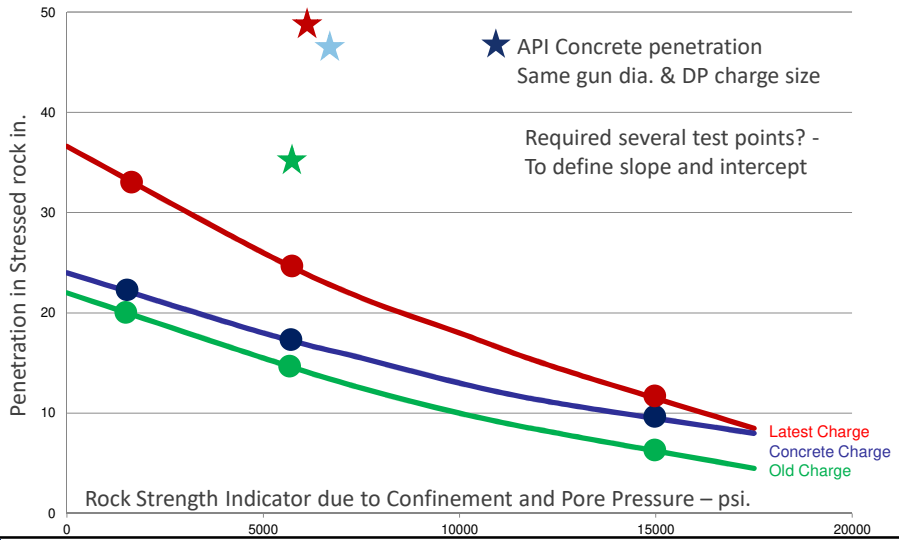
Section 5

- Measures the amount of gun debris
  - Gun section is shot under controlled atmospheric conditions.
  - Debris measured outside the gun
  - Debris measure remaining in the gun.

Measuring Perforator Performance

- Not only was Sect 1 concrete penetration impossible to corelate with sandstone, but it was used to sell charges.
- Penetration of 60in was seriously offered as a charge performance in a real reservoir.
- It was well known that under confined conditions and in a moderately hard rock 18in was a more realistic penetration.
- And that every rock behaves differently – porosity, grain size, cementitious material, type of sand and many more variables are involved.

Measuring Perforator Performance

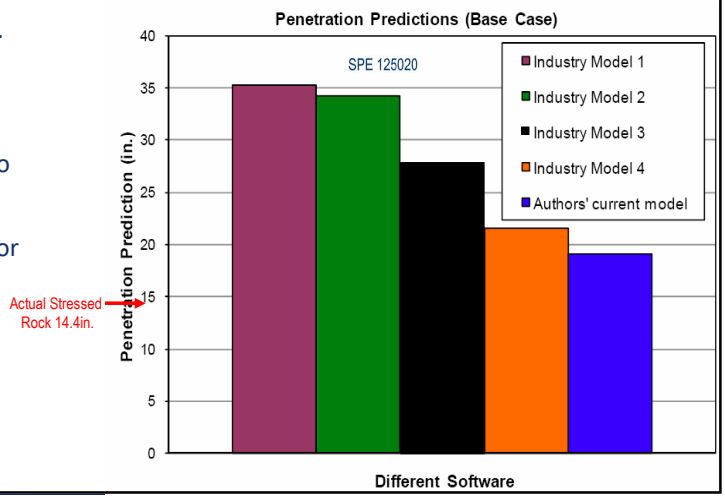


Downhole Perforator Performance

- There are new extreme requirements for perforators in HPHT or deep or hard rock or low permeability reservoirs and combinations of all.
- Not a case of punch some holes and let it flow.
- Last slide showed how different stress and rock conditions will greatly limit perforator performance and how some perforators work better under specific conditions.

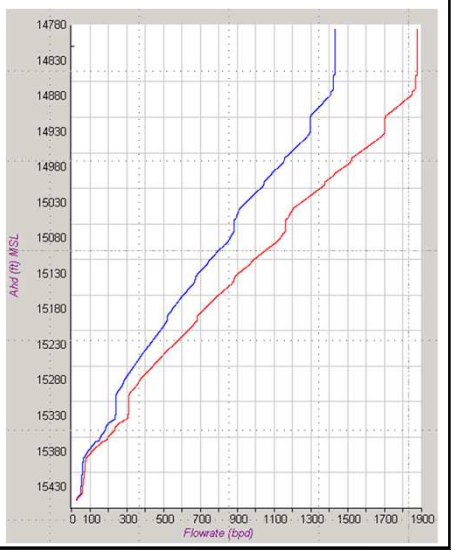
Downhole Perforator Performance

- Models at the time, mostly working from concrete penetration largely ignored overburden and pore pressure altogether.
- Result was that a 4000psi UCS rock could have a penetration higher than concrete, because the concrete UCS was say 5,500psi. The fact that overburden pressure was 12,000psi was not taken into account.
- For inflow modeling at the time we typically used a 30 or 40% correction factor as a rule of thumb to downgrade the penetration given by the contractor.
- Once we developed models that included downhole conditions, there was no need for the large correction factors.



Downhole Perforator Performance

- Using actual stressed rock penetration data for 2 guns, we can see in an inflow model that one gun has a significant inflow advantage to the other.
- This may be used to justify the additional cost of the higher performing gun.



Review of the new API RP 19B

- So far we have seen that the 19B Second Edition was geared heavily towards using concrete as a consistent test material, even though it was of no use for corelating to downhole conditions.
- The drive to develop a useful standard that would be cost effective for the Contractors and Manufacturers as well as being of genuine value to the Operators was complex and time consuming.
- There were many great ideas to generate things like low cost synthetic target materials (effectively porous concrete), but there was also a need to keep it as simple as possible.

Review of the new API RP 19B

- New section numbering has been introduced to the new 3rd edition, due to a new API document specification, however the old section numbers have been included in the titles for easy reference.

Review of the new API RP 19B

New Section 1

- 4.1 Evaluation of Perforating Systems under Surface Conditions, Concrete Targets
  - The purpose of this section is to describe recommended practices for evaluating perforating systems using concrete targets under multiple shot, ambient temperature, and atmospheric pressure test conditions.
  - Basically the same as previous edition, however there is allowance for testing mixed charge systems, which have become more popular.
  - Also states on the data record sheets that – *Penetration data recorded in API RP 19B Section 1 may not directly correlate to penetration downhole*.

Review of the new API RP 19B

New Section 1

- 4.1 Evaluation of Perforating Systems under Surface Conditions, Concrete Targets cont.
- This statement is weak and should more clearly indicate that there is no useful correlation between ambient concrete and in-situ performance.
- During our 19Bcommittee meeting in May 2019, I challenged the use of the weak statement. On a unanimous vote it was decided to change the statement for something like. *Penetration data recorded in API RP 19B Section 1 does not correlate to penetration downhole.*
- But this test is an essential whole gun section test to identify charge interference and relative performance of individual charges.
- If you look closely at a Sect. 1 test result you can see the often wide variation in penetration due to charge consistency and or target consistency.

Review of the new API RP 19B

New Section 2

- 4.2 Evaluation of Perforators using Stressed Rock Targets
  - This provides a basis for the evaluation of perforators using rock cores at simplified in-situ conditions. Provides useful data on penetration depth as a function of target composition and state.
  - Designed to provide a first order estimation of downhole performance, given suitable predictive models.
  - As all Sect.2 facilities are different, including OD of target. A detailed comparison test program was instigated to ensure that all test facilities provided consistent results. A single set of outcrop targets were distributed with a single run of charges to all facilities. Results were surprisingly consistent.

Review of the new API RP 19B

New Section 2

- 4.2 Evaluation of Perforators using Stressed Rock Targets
  - There will be 3 Test confinement pressures - 1500 psi, 5500 psi and 9500 psi
  - There will be 4 shots at each pressure
  - The following will be recorded
    - Casing hole dimensions
    - Total core penetration
    - Total target penetration
    - For first time provides a completely comparable data set for any charge.

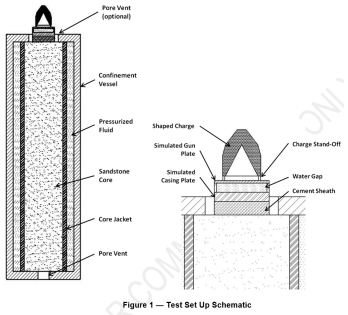


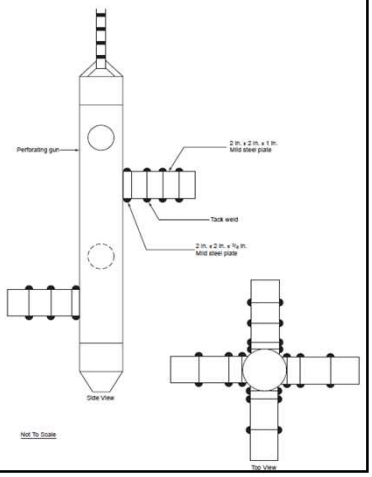
Figure 1 — Test Set Up Schematic

For the first time the tests can be officially witnessed and recorded

Review of the new API RP 19B

New Section 3

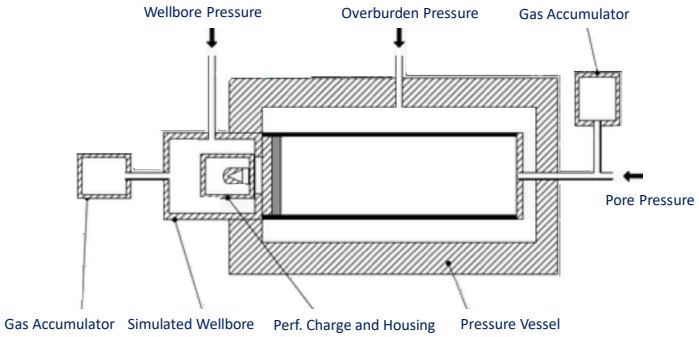
- 4.3 Evaluation of Perforator Systems at Elevated Temp. Conds.
  - This has become more important
  - More elevated temperature operations
  - More detailed procedures and alternate tests
  - Otherwise still generally unchanged



Review of the new API RP 19B

New Section 4

- 4.4 Eval. of Perforation Flow Perf. Under Simulated DH Conds.
  - Provides a basis of comparison for the development and evaluation of perforators, and perforator performance thru flow from rock targets shot under simulated in-situ conditions.
  - A far more detailed standard has been prepared to enable the use of Sect. 4 under more varied conditions.



Review of the new API RP 19B

New Section 4

- 4.4 Eval. of Perforation Flow Perf. Under Simulated DH Conds. Cont.
  - Sect. 4 is a critical test, to understand in detail why charges shot under different conditions can result in significant changes in inflow performance.
  - Enables widely different test facilities to come under the same standard.
  - Has details on the measurement and calculation of CFE – Core Flow Efficiency and PI – Productivity Index.
  - Particularly important in the understanding of flow performance under different dynamic conditions.
  - Conditions in the simulated wellbore and in the simulated gun housing, as well as the response time and size of the accumulators have a large impact on the dynamic events taking place in the charge hole.

Review of the new API RP 19B

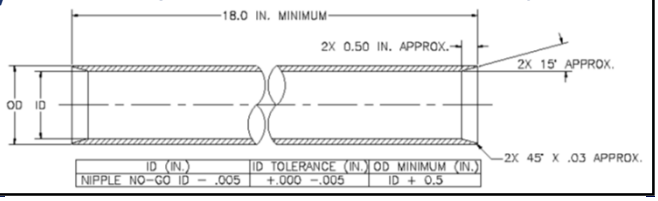
New Section 5

- 4.5 Debris Collection Procedure for Perforating Guns
  - Due to complexity in well conditions, it is not possible to develop a surface test to determine the amount of gun debris left in the well.
  - However this test does provide a reasonable measure of the relative performance of different gun systems, tested under these controlled conditions.
  - Delivers the amount of debris exiting the gun exiting the gun on firing and the amount of debris exiting the gun after rolling the gun.
  - A sieve size analysis is also performed and the gun exit holes are measured.

Review of the new API RP 19B

New Section 6

- 4.6 Evaluation of Perforator Systems to Determine Swell
  - Swell testing is critical, especially for thru tubing operations. We need to know if the gun is going to swell beyond the minimum ID of the completion.
  - The results indicate the gun swell in 2 dimensions along the length.
  - In the case of 2-7/8in or less dia. Guns – an 18in long no-go tube will be used, this is not mandatory for larger dia. Guns.
  - Smaller dia. Guns have a tendency to not only swell but to bend as well, hence the 18in tube.



Review of the new API RP 19B

Proposed Section 7

- Evaluation of Perforators for Hole Size Performance in Alternate Casings
  - Designed to provide accurate hole sizes in casings under ambient conditions
  - Enables multiple grades/diameters/weights of casing to be tested on one gun section.
  - Provides useful data on hole size and conformation, burr height and the effect of gun clearance. Can be shot in different fluids and air.

Conclusion and Take Aways

- Key acknowledgement by Contractors that the use of Sect. 1 Concrete penetration was not suitable for correlation to in-situ reservoir and well conditions.
- A major paradigm change and significant cost to contractors and manufacturers in building Sect. 2 and some Sect.4 Test facilities, as well as starting to carry out the Sect. 2 testing.
- More stressed rock testing then drove the acceptance that existing models to convert concrete and stressed rock data into down hole penetration were inadequate, as they did not take into account the impact of overburden pressure and pore pressure adequately.
- Industry worked together with Operators very successfully to make the changes needed, with a large amount of personal effort from the sub-committees.

Ongoing API work in Perforating

- The API are currently sponsoring our work on 'The Time/Temperature Thermal Decomposition and Stability of HMX' with Lawrence Livermore NL using ODTX* test cells.
  - With complex offshore floater perforating jobs, there can be conditions when time to run guns and in an emergency pull them out safely can take weeks.
  - Existing test data on extended temperature was limited.
  - First phase of work is complete and 2019 work is now scheduled to identify the time temperature limits for HMX.

* *One-Dimensional-Time to Explosion*

Ongoing API work in Perforating

- 'The Time/Temperature Thermal Decomposition cont.

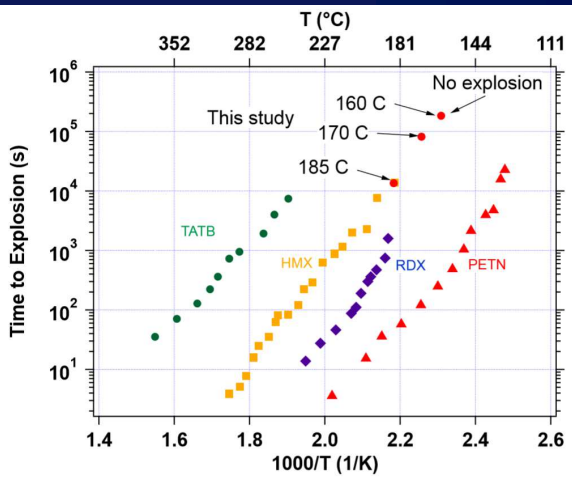


Figure 12. ODTX test data at 160 °C, 170 °C, and 185 °C (in red dot) The test data at 185 °C matches very well with the historical test data collected at LLNL (12,456 seconds at 185 °C for current study, 13,718 seconds at 184.5 °C from the historical data).

Useful Resources

- The SPE has a large database of papers on Perforating
- The API – www.API.org, is the go-to location for up to date data sheets on charge performance, as well as perforating standards.
- The International Perforating Forum – is the dedicated global organization for Perforating. www.perforators.org will link you to numerous conference presentations on perforating, a perforating safety database and the Journal of the International Perforating Forum – all free.

Questions?