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Designing Shaped Charges to Perform In Reservoir Rock

IPS 16-45

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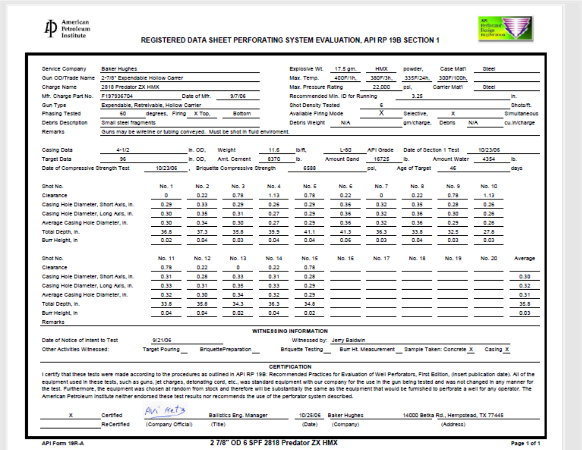
Agenda

- Introduction
- Objectives
- Design Process
  - Flow Laboratory
  - Computational Modeling
- Results
- Conclusions

Introduction

- Most industry models (used for predicting penetration) are based on API-Section I concrete based tests.
- A standard model may predict 23.43” in Berea sandstone for a Deep Penetrator (35.8” TTP Section I).
- In reality, penetration for this charges was measured to be 11.13” in an API Section-IV test under downhole conditions.
- This example clearly highlights how penetration models can be misleading when making critical job design decisions.
- We have also conducted laboratory experiments and compared measured data with advanced penetration models and comparisons have shown a discrepancy of up to 50%.

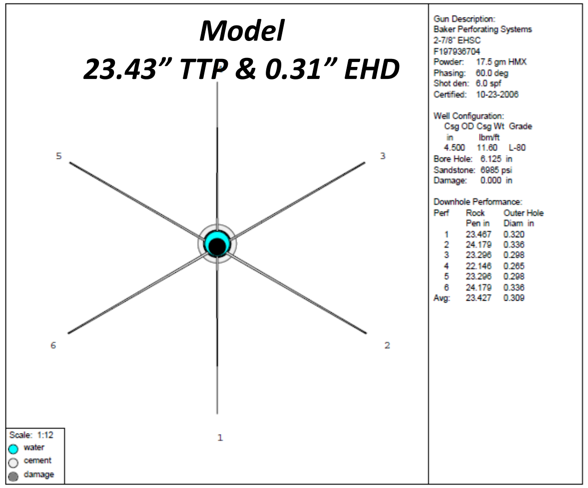

American Petroleum Institute

REGISTERED DATA SHEET PERFORATING SYSTEM EVALUATION, API RP 19B SECTION 1

API Form 19R-A — 2 7/8" OD 6 SPF 2818 Predator ZX HMX — Page 1 of 1

Section I
35.8” TTP & 0.31” EHD

Section IV
11.13” TTP & 0.29” EHD



Model
23.43” TTP & 0.31” EHD

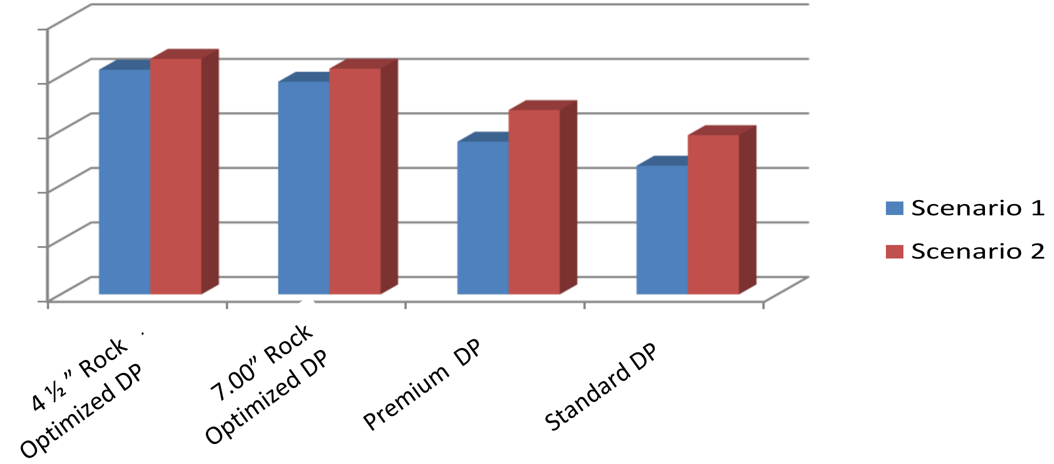
Introduction

- Several factors influence penetration characteristics
  - Pressures (wellbore to pore to confining)
  - Internal Stand-Off and Water Gap
  - Rock properties (bedding plane orientations, porosity, permeability, UCS etc.)
  - Cement and casing material strength and thicknesses.

- None of the models that exist in the industry are capable of accounting all of the above factors (in particular, the natural variances and anomalies that exist in a rock) while modeling penetration.

- A scientific and engineered approach is the best way to *design a shaped charge for reservoir conditions.*

Objective: Optimize Charge Design



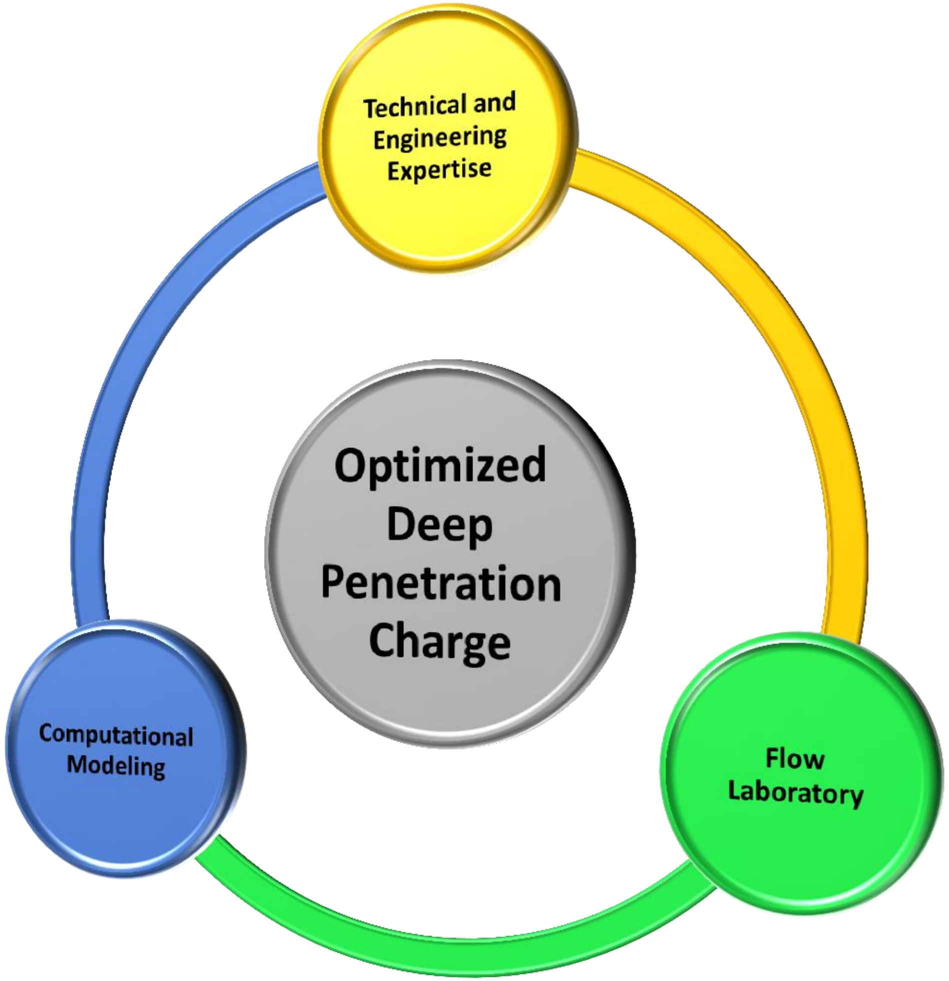
Scenario:

- Shaped charges for oilfield perforating have long been evaluated on the basis of their performance in concrete targets shot at ambient conditions, failing to clearly evaluate performance at downhole conditions.

Solution:

- By designing a shaped charge around performance at true downhole conditions has enabled significant performance and therefore productivity improvements.
- The Rock Optimized Deep Penetrating Shaped Charge has been designed and optimized in this way. Utilizing high-end numerical modeling and extensive testing on reservoir rocks at downhole conditions, can achieve up to 47% of additional penetration in some of the most challenging reservoir conditions.

Design Process

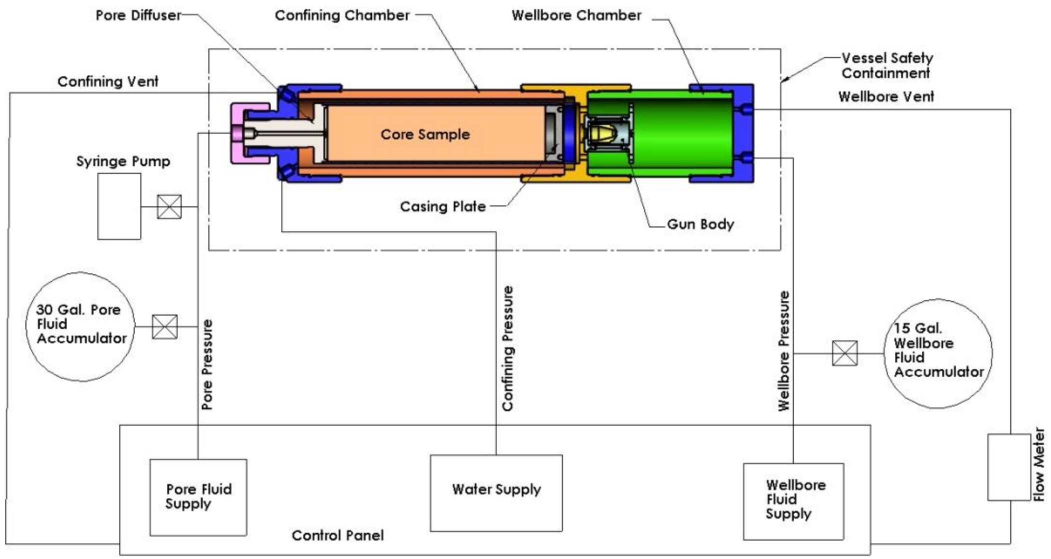


- Technical and Engineering Expertise
  - ✓ Charge Design
  - ✓ Charge Optimization
- Flow Laboratory
  - ✓ Standard Section-II
  - ✓ Modified Section-II
  - ✓ Section-IV
- Computational Modeling
  - ✓ Hydrocode
  - ✓ Computational Fluid Dynamics

Perforation Flow Laboratory

The flow laboratory provides the capabilities to:

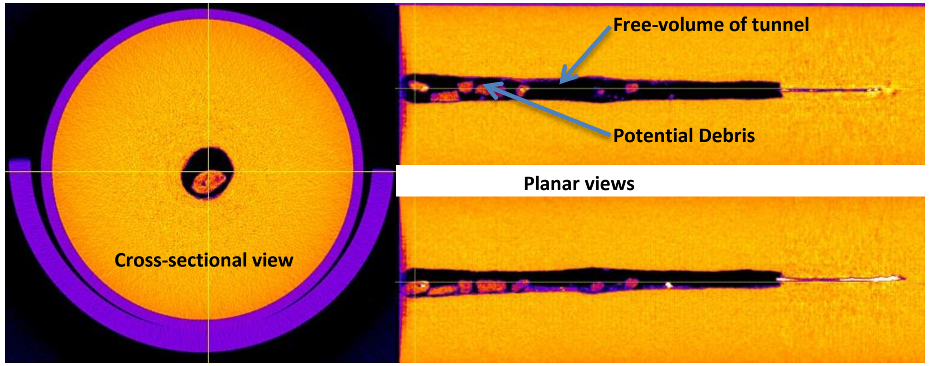
- Study and qualify the performance of different perforating systems in formation rock at reservoir conditions.
- Study the influence of various factors on well productivity.
- Integrate this knowledge to select the optimal perforating system and clean up strategy for improved productivity.

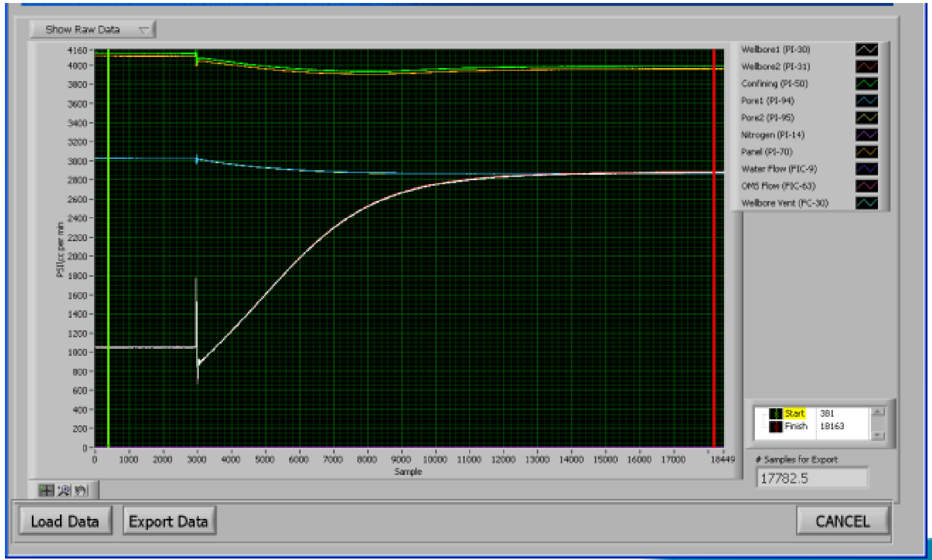


	Section-I	Section-II	Section-II Modified	Section-IV
Target	Concrete	Analog Rock	Analog Rock	Analog Rock
Confining Pressure	Atmospheric	10000	25000	15000
Fluid	Not Applicable	Saturation fluid (OMS)	OMS/Brine	OMS/Brine
Wellbore Pressure	Not Applicable	Not Applicable	25000	10000
Pore Pressure	Not Applicable	Not Applicable	25000	10000
Temperature	Not Applicable	500F	300F	300F
Pre-shot Flow	Not Applicable	Not Applicable	Not Applicable	Applicable
Post-shot Flow	Not Applicable	Not Applicable	Not Applicable	Applicable

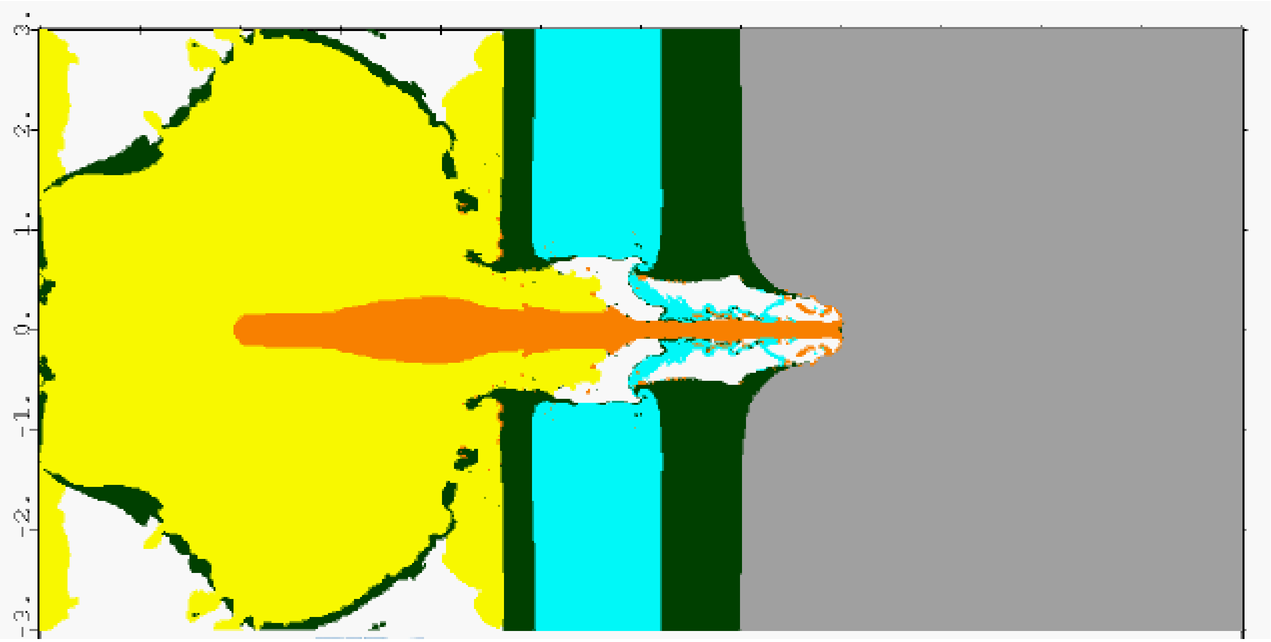
Perforation Flow Laboratory - Measurements

- Pre-shot porosity
- Pre/post perforation permeability
- Perforation tunnel diameter
- Perforation tunnel depth
- Detailed tunnel characterization using advanced CT scanning methods
- Dynamic pressure data
- Core flow efficiency and productivity ratio
- Evaluate perforation cleanup mechanisms
- Optimization of underbalance methods

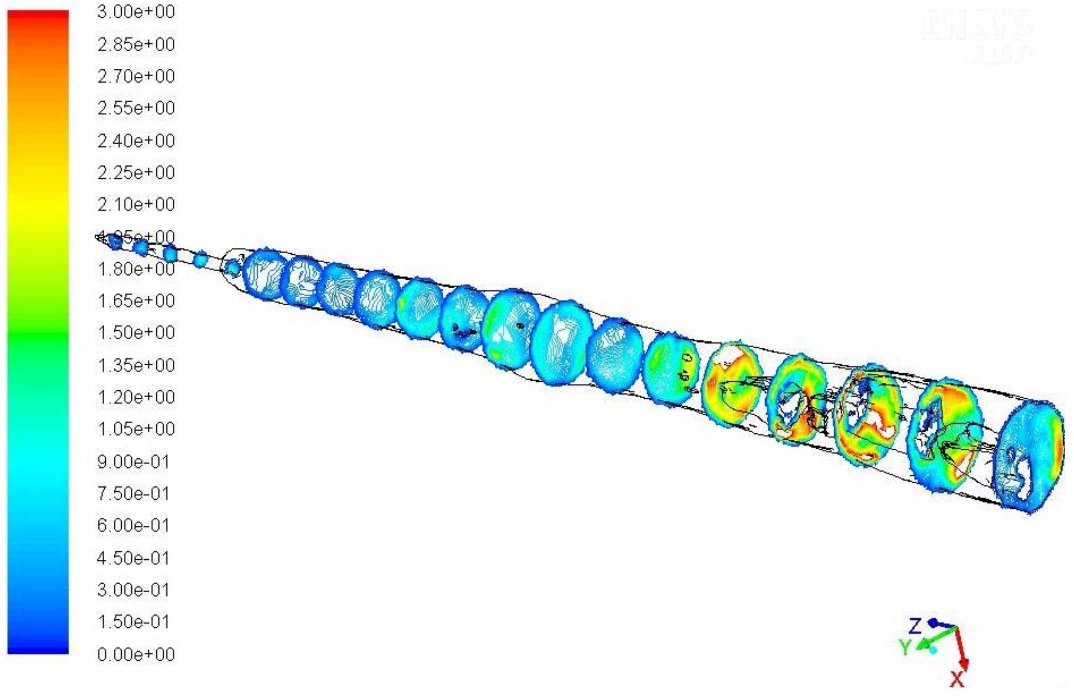




Computational Modeling



Hydrocode modeling for shaped charge design to change various parameters which will enhance charge performance in reservoir rock



Computational Fluid Dynamics – Export actual tunnel geometry from CT Scans & input flow lab flow data to predict well flow.

Shape charge Penetration: Section-I & 2

- Irrespective of charge size, penetration characteristics are quite different in a true downhole condition test when compared to Section-I.
- Based on existing test data, pore pressure does seem to have an influence on charge performance.
- Modified Section-II testing is the recommended method to evaluate/understand shaped charge performance.

	Comparison			
	Charge	Section I Rank	Section II Rank	Modified Section II Rank
2-7/8"	Charge 1	3	2	**1**
	Charge 2	4	1	**2**
	Charge 3	2	n/a	**3**
	Charge 4	1	n/a	**4**
4-1/2"	Charge 1	3	2	**1**
	Charge 2	1	1	**2**
	Charge 3	2	3	**3**

Rock Specific Modified Section-2 Testing

		Section-II Berea, no pore or wellbore	Modified Section-II Carbon Tan	Modified Section-II Buff Berea
Pressure Conditions (psi)		9500	10370, 6960, 7250	9300, 6000, 5500
Rock Optimized Charge, HMX	TTP, avg,	18.2”	19.8”	21.0”
	EHD, avg	0.40”	0.30”	0.33”
Premium Deep Penetrator, HMX	TTP, avg	20.2”	14.0”	16.9”
	EHD, avg	0.33”	0.29”	0.32”
Standard Deep Penetrator, HMX	TTP, avg	14.8”	11.8”	14.6”
	EHD, avg	0.42”	0.37”	0.37”

API Section-4 Testing

- Rock Optimized perforating charge provides improved Surface Area in the perforation tunnel, thereby providing better productivity.
- Testing conducted with Buff Berea Sandstone core under similar conditions

Tier	Shaped Charge	Core Penetration	Perforation Diameter (Casing)	Perforation Diameter (Tunnel)	Perforation Surface Area	Productivity
Best	Rock Optimized	18.25 in.	0.29 in.	1.24 in.	36.7 sq.in	1.56
Better	Premium Deep Penetrator	16.00 in.	0.31 in.	1.02 in.	26.5 sq.in	1.14
Good	Standard Deep Penetrator	13.31 in.	0.36 in.	0.76 in.	16.3 sq.in	1.07

Conclusions

- A scientific and engineered approach is the best way to design a shaped charge for reservoir conditions (rather than Section-I/II or predictive models)

- Utilizing sophisticated numerical modeling and extensive testing on reservoir rocks at downhole conditions, **a shaped charge for reservoir specific conditions has been developed**.

- <u>Applications</u>
    - Natural or Stimulated completions, producers or injector wells
    - Oriented perforating strategies
    - Onshore and Offshore environments
    - Ultra high pressure/high temperature completions
    - Extended reach and highly deviated wells
    - Tubing conveyed, wireline or coiled tubing conveyed perforating

- <u>Features and Benefits</u>
    - Increases production or injection by deeper formation connectivity with the wellbore
    - Ensures perforation contribution efficiency

QUESTIONS? THANK YOU!