RDX vs HMX PERFORMANCE IN MODERN PERFORATING

2018-NAPS-31

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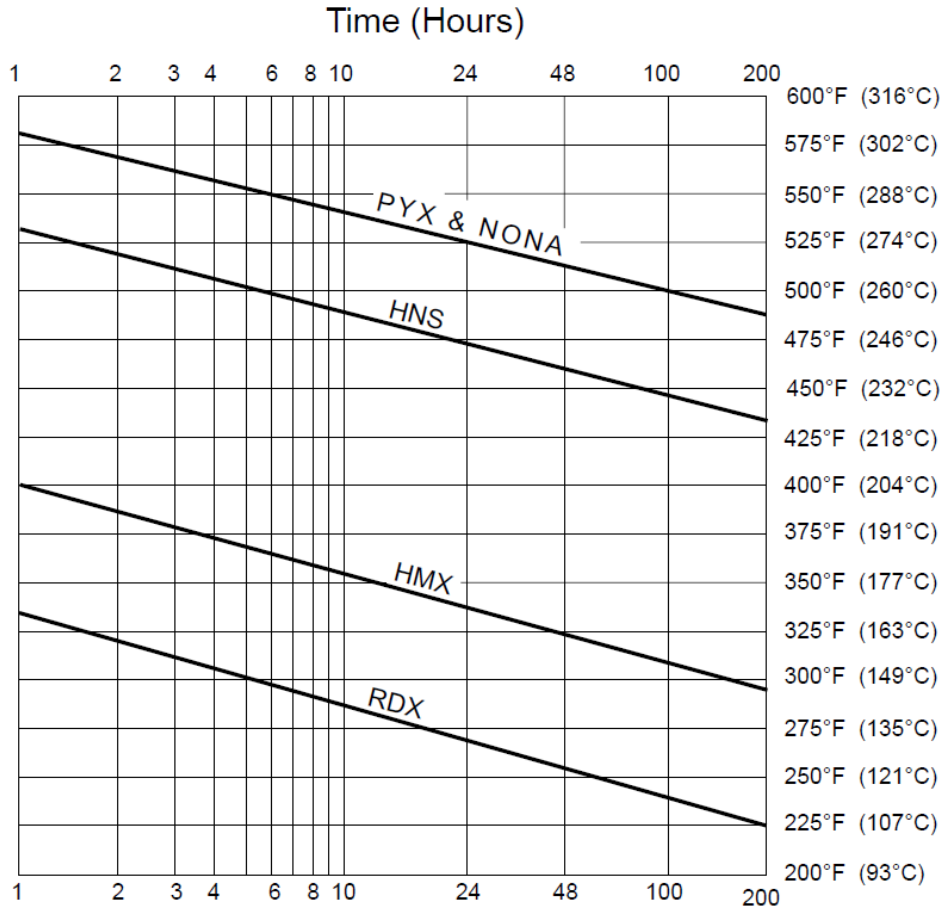
Common Misconceptions

What we as a manufacturer heard during the downturn…

- RDX will never auto-detonate from thermal runaway, so it must be safer. Only HMX is dangerous with temperature exposure
  - False, RDX has a critical temperature for thermal runaway and is only rated to 325°F
- If my perforators are HMX, my gun system can be rated for 400°F even if I use RDX cord/detonator
  - False, your system is rated to the lowest temperature component
- Everyone certifies HMX for API RP19B, so it must be for the better performance over RDX
  - Most often it was because API required 300 charges for a HMX test and 1,000 for a RDX
- Why can't you make an RDX version of these charges?
  - Most manufacturing companies do offer the same charge in RDX and HMX

Conventional Explosive Types

Explosive Type	Theoretical Maximum Detonation Velocity	Maximum Temperature Rating
PETN	~8.29 km/s	225°F for 1hr
RDX	~8.80 km/s	325°F for 1hr
HMX	~9.15 km/s	400°F for 1hr
HNS	~7.00 km/s	500°F for 1hr
PYX	~7.20 km/s	600°F for 1hr



Historical Perspectives

RDX vs HMX

- HMX shows a detonation velocity increase of 4-6%
- No significant differences in ambient impact sensitivity
- Explosive Energy output 4-6% greater in HMX at TMD (voidless)
- Detonation Pressure is 12-13% higher in HMX at TMD
- Historical military testing showed shaped charge performance variation of 7.6% between HMX and RDX
- Primary conclusion was that due to cost increase in HMX, the only significant difference and benefit to HMX is in the thermal properties and stability

Data Source: HMX as a Military Explosive, US Naval Ordnance Laboratory, 1956

Modern Day Standards

API RP 19B

- Section 1 full system performance
  - Tests are very expensive to conduct, most companies are not going to certify both RDX and HMX in the same charge design
  - Pre 2014 Edition 3 it required 1,000 RDX charges, 300 HMX charges, and 300 HNS charges
  - Most will have a general disclaimer “Charges are available as RDX, HMX and HNS versions”

- It is estimated that usage is approximately 85% RDX / 15% HMX / <1%HNS

- From 370 API data sheets pulled from eight manufacturing companies
  - 15% RDX / 80% HMX / 5% HNS
  - If bulk majority of charges sold are RDX, why is the bulk of testing done in HMX?

Hole Size Test Setup

"Section 7" Type Test

- Test utilized the same charge, but of various lot dates
- 3.125" 6spf spacing at 60° phasing, various overall gun lengths
- All tested in 5.5" 23# P-110 casing
  - Fluid, no outer cement confinement

Hole Size Performance in CH Perforators

Examination of performance in modern day consistent entry hole charges

Gun Size / Total Shots	Average Hole Size		
	RDX	HMX	*% Diff*
3.125” Gun / 3 Shots total	0.36”	0.36”	*0.9%*
3.125” Gun / 4 Shots total	0.34”	0.32”	*5.6%*
3.125” Gun / 6 Shots total	0.35”	0.33”	*4.6%*
3.125” Gun / 6 Shots total	0.37”	0.36”	*1.1%*
3.125” Gun / 7 Shots total	0.36”	0.36”	*0.2%*
3.125” Gun / 9 Shots total	0.36”	0.35”	*0.8%*

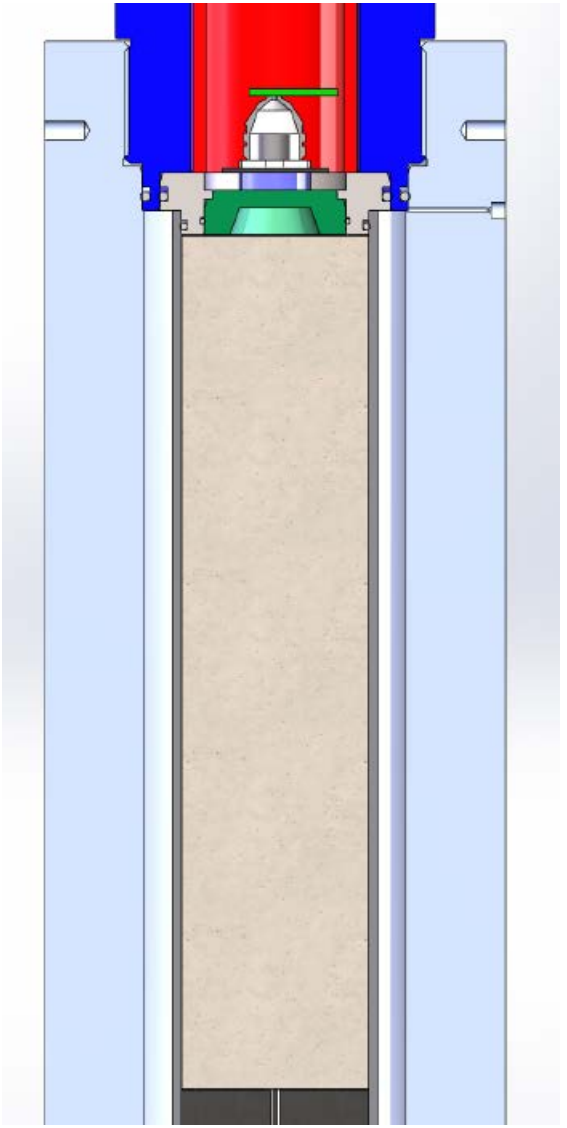
- Did not appear to be significant variation in performance due to explosive type

API RP 19B Section II

Section II Type Test Setup

- Berea Sandstone, Parallel bedding planes
  - UCS average = 6231psi
  - Porosity average = 19.85%

- Stress state
  - Overburden pressure of 5500psi
  - Pore pressure of 0psi



Penetration Performance in SDP Perforators

Examination of penetration performance in modern day Super Deep Penetrating style charges

- Two shots at each stress state were conducted and reported as an average in below data set

Charge Size / N.E.W.	RDX Performance			HMX Performance			% Diff
	UCS	Porosity	TTP	UCS	Porosity	TTP	
2.75" / 15gm	6200psi	19.54%	**13.13"**	5768psi	20.47%	**13.38"**	***-1.9%***
3.125" / 21gm	6334psi	19.62%	**15.19"**	6213psi	19.73%	**15.69"**	***-3.2%***
3.375" / 25gm	6424psi	20.17%	**16.69"**	6360psi	19.69%	**19.56"**	***-15.9%***
4.5" / 39gm	6622psi	19.90%	**16.81"**	5930psi	19.73%	**18.41"**	***-9.1%***

- Did not appear to be significant variation in performance due to explosive type in <21gm charges
- ~16% variation in 25gm charges was unexpected, even though test conditions appeared closely matched
- 39gm charges had a significant change in UCS that may have influenced the data

Conclusions

Based on the Data…

- Does not appear to be significant variations in performance
  - Hole Size average variation was 2.2%
  - Penetration average variation was 7.5%
- Only examined two charge types, other designs and other manufacturers may be affected differently
- Typically the expense of certifying charges in both RDX and HMX is not cost effective
- It is always important to understand all the explosive components in your system and make sure you select the correct products to meet your completion needs

Moving Forward

Challenges we face in our industry

- Frequent cycles of “boom and bust”
  - Creates a feeling of revolving door employees constantly requiring new training
- Education for ourselves and customers never stops
  - It is our duty as the manufacturer and the developer of the technology to do our due diligence and educate people correctly
- Technology continues to advance
  - Constant evolution and change in products, methods, raw materials, etc requires everyone to adapt with it
- While this topic may seem trivial or common knowledge to some, there are those out there that need this type of information and material

QUESTIONS? THANK YOU

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