2017 International Perforating Safety Forum

A Brief Study on the Potential Hazards of a Misfired Perforating Gun

IPSF 17-08

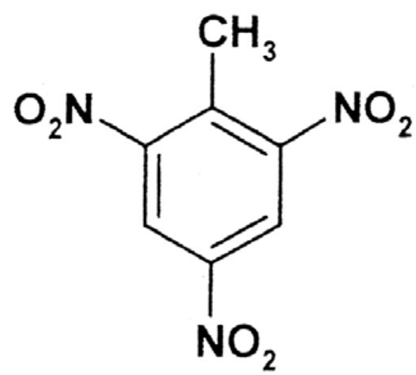
AUTHORS: Ben Potter – Owen Oil Tools

Introduction

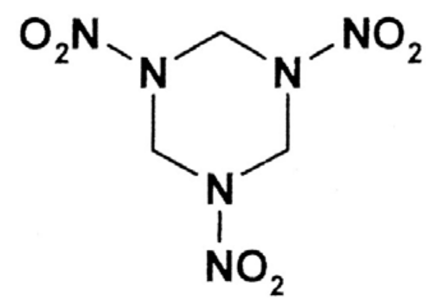
- More often than not, perforating operations occur without issues.
- In the rare case of partially fired guns that do not result in a burst gun carrier, operators are advised to follow RP-67 procedures prior to downloading of gun.
- Unknown gases and pressures may exist in gun that can pose a hazardous situation to operators

Background

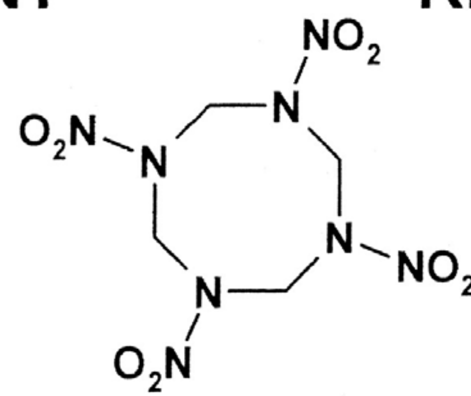
- Most perforating guns utilize CHNO based explosives, which include PETN, RDX, HMX, & HNS.
- TNT also CHNO based, but not common in perforating guns.
- CHNO reaction generates gaseous products such as N_2, H_2O, CO, CO_2, O_2, and minor traces of NO_x.
- These gases can become trapped in gun carrier resulting in increase of internal pressure.



TNT



RDX



HMX

CHNO Reaction Hierarchy

- Reaction Hierarchy "Rules of Thumb" for CHNO.
  1. All Nitrogen forms N_2.
  2. All Hydrogen is burned to H_2O.
  3. Any oxygen left after H_2O formation burns to carbon to CO.
  4. Any oxygen left after CO formation burns CO to CO_2.
  5. Any oxygen remaining forms O_2.
  6. Traces of NO_x (mixed oxides of nitrogen) are always formed.

- For Example:

(PETN) $C_5H_8N_4O_{12}$ = 5C + 8H + 4N + 12O

  1. $4N \rightarrow 2N_2$
  2. $8H + 4O \rightarrow 4H_2O$ (8 Oxygens remaining)
  3. $5C + 5O \rightarrow 5CO$ (3 Oxygens remaining)
  4. $5CO + 3O \rightarrow 3CO_2 + 2CO$
  5. No oxygen remaining for O2 formation.

- $C_5H_8N_4O_{12} \rightarrow 2N_2 + 4H_2O + 2CO + 3CO_2$

Reference: Cooper, Paul W. "Chapter 12." *Explosives Engineering*. New York, NY: VCH, 1996. 153-58. Print.

Example

- This subject is best taught by example:
- Assume 400g RDX reacts inside 3-1/8” x 4’, 6spf gun carrier.
- Vessel originally at STP conditions (75°F & 14.7psi) with 174.4in^3 free volume.
  - 41in^3 of this free volume is made up of consumable explosive.
- Assume low order reaction resulting in no bursting of vessel. All gas products trapped inside.

Free Air

- Account for existing N_2 and O_2 already in vessel.

$$\#mole\ air = \frac{Free\ Volume}{Volume\ of\ Air\ @\ STP} = \frac{174.4 in^3}{1{,}493\ ^{in^3}/_{g\ mole}} = 0.117\ g\ mole$$

- Air ≈ 79% N_2 + 21% O_2. Therefore:

$$n_{O_2} = 0.117 \times 21\% = 0.025\ g\ mole$$
$$n_{N_2} = 0.117 \times 79\% = 0.092\ g\ mole$$

Determine Gas Products

- Need to determine # moles of RDX.

$$n_{RDX} = \frac{N.E.W.}{Molecular\ Weight} = 1.80\ moles$$

Explosive Material	Molecular Weight (g/mole)
TNT	227.1
RDX	222.12
HMX	296.16
HNS	450.23
PETN	316.14

- For RDX, reaction hierarchy is

$$1.80C_3H_6N_6O_6 \rightarrow 5.40N_2 + 5.40H_2O + 5.40CO$$

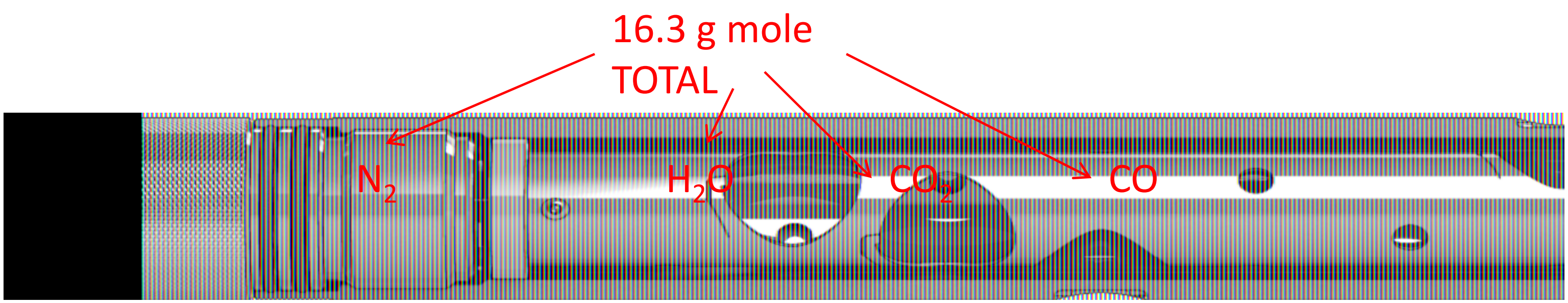
- Upon combustion, CO will react with O_2 already in vessel to form CO_2.

$$\therefore 1.80C_3H_6N_6O_6 + 0.025O_2 \rightarrow 5.40N_2 + 5.40H_2O + 5.35CO + 0.05CO_2$$

Total Gas Products

- Total gas in vessel is as follows:
  - n_{N2} = 0.092 + 5.40 = 5.49 g mole
  - n_{H2O} = 5.40 g mole
  - n_{CO} = 5.35 g mole
  - n_{CO2} = 0.05 g mole
  - n_{TOTAL} = 16.3 g mole

- We now know the amount of gas in the vessel after reaction.



Determine Pressure

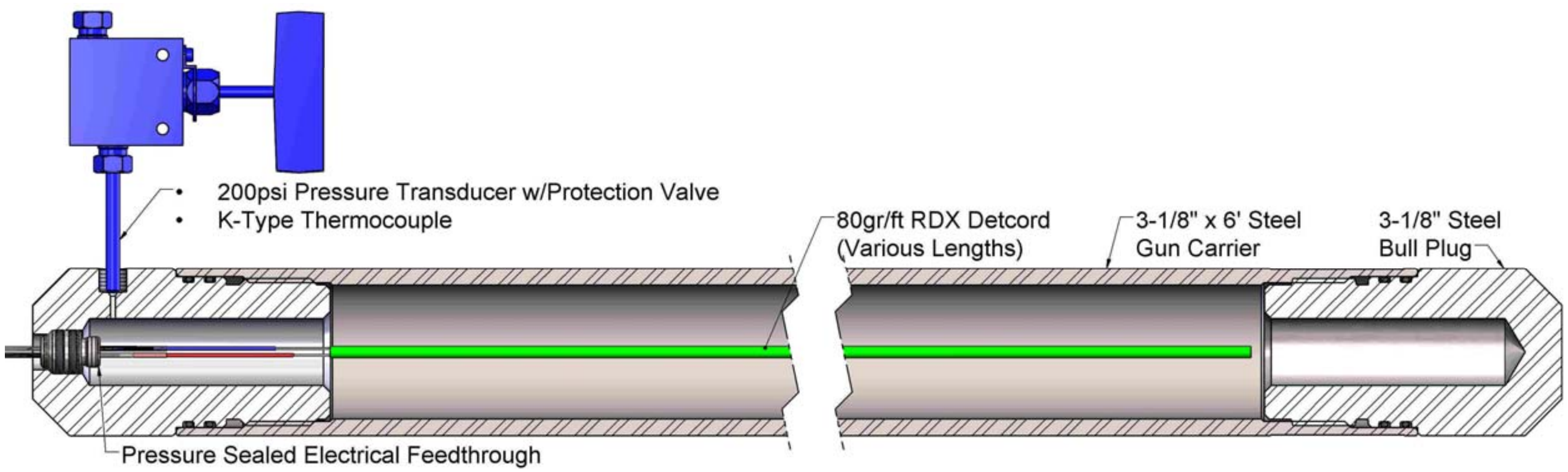
- Pressure can be calculated by Ideal Noble Gas Law, PV = nRT.
- We know Volume (V), # moles gas (n), Universal Gas Constant (R), and can assume temperature (T) has cooled down to ambient temperatures (75°F) after RP-67 procedures are followed.
  - New free volume should account for explosive consumed during reaction, if known. $174.4 in^3 + 41 in^3 = 215.4 in^3$
- Predicted trapped pressure inside gun carrier is

$$P = \frac{nRT}{V} = 2{,}345\ psi$$

- Over a 0.25” ID equates to 117 lb_f!

Testing

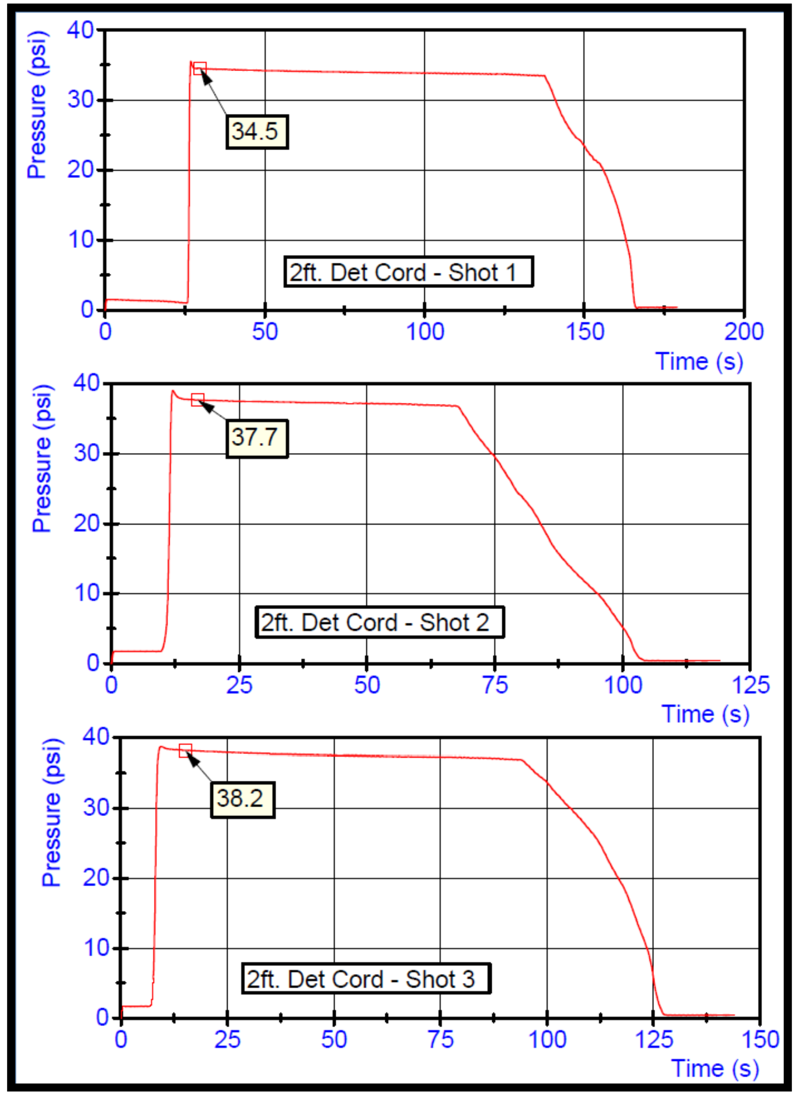
- Small scale testing performed to confirm predictions.
- 3-1/8" x 6' gun carrier (no scallops) used with sealed bull plugs on each side. Pressure and wire feedthrough installed into bull plugs for instrumentation measurements.
- Intentionally detonated 80gr/ft RDX detonating cord initiated by RDX EBW.
  - Detonation vs. deflagration reaction products are same. Velocity of reaction is different.
  - Detonation will generate higher peak pressure but will settle down to static pressure after reaction.



Test Data

- 200 psi transducer.
- K Type thermocouple probe used to sample gas temperature.
- Sampling rate = 100 samples / sec.

N.E.W.	Predicted Static Pressure	Measured Static Pressure	Static Temperature	% Error
2ft RDX Detcord w/EBW (10.85 g)	42 psi @ 80 °F	34.5 psi	70 °F	17.9%
		37.7 psi	80 °F	10.2%
		38.2 psi	80 °F	9.0%
	Averages	**36.8 psi**	**76.7 °F**	**12.4%**
	Standard Deviation	**1.6**	**4.7**	**3.9%**
3ft RDX Detcord w/EBW (16.05 g)	60 psi @ 120 °F	61.3 psi	120 °F	2.2%
		64.6 psi	125 °F	7.7%
		59.7 psi	120 °F	0.5%
	Averages	**61.9 psi**	**121.7 °F**	**3.5%**
	Standard Deviation	**2.0**	**2.4**	**3.1%**
4ft RDX Detcord w/EBW (21.25 g)	75 psi @ 120 °F	78.0 psi	115 °F	4.0%
		80.4 psi	120 °F	7.2%
		81.6 psi	122 °F	8.8%
	Averages	**80.0 psi**	**119.0 °F**	**6.7%**
	Standard Deviation	**1.5**	**2.9**	**2.0%**



Future Testing

- Need to validate predictions on larger more realistic scale.
- Perform larger scale testing with increased N.E.W. in 3-1/8” and 7” carriers.
- Intentionally deflagrate material to reduce likelihood of carrier burst during reaction.
- Use data in effort to fully validate predictions. Use predictions to estimate potential pressures in all common size guns for operator reference.

Potential Hazards

- No current way of determining how much reaction or what is trapped in the perforating gun prior to downloading.
  - Currently all service companies can do is measure the external temperature of the gun to determine if it is ‘cooking off’ or cooling down

- This poses a large safety concern for the operators downloading.

- Large concentrations of CO_2 can be noxious to humans.

- Other materials can produce additional CO_2 and Hydrofluoric (HF) gases as a byproduct.
  - Explosive additives / binders, such as Viton™ or Teflon ™ contain fluoride polymers
  - Many companies use FKM sealing products in perforating systems that potentially could react in some scenarios

How Do We Prepare?

- There is no current industry standard practice for downloading of misfired guns that may contain trapped pressure.
- What is the best practice and how should the industry approach this?
  - Are there common practices amongst service companies?
  - Do companies have proprietary procedures for this?
- Ideal solution
  - Remove personnel from hazard zone.
  - Use a remotely activated piercing tool to safely vent gas pressure in a well ventilated area.
  - Conduct operation in a controlled manner with minimal risk and human interaction.

Conclusion

- Pressure predictions appear to be accurate, although larger scale testing needs to be conducted to confirm.
- Predictions can be used to generate reference chart of common gun sizes and potential trapped pressures that may exist.
- Always follow RP-67 recommended procedures for retrieving misfired guns.
- What are best downloading procedures? How can pressure be safely vented at wellsite?
  - Does there need to be a more detailed Operations Guide for these instances?

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QUESTIONS?
THANK YOU!

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