High Performance $BKNO_3$ Igniter Formulations

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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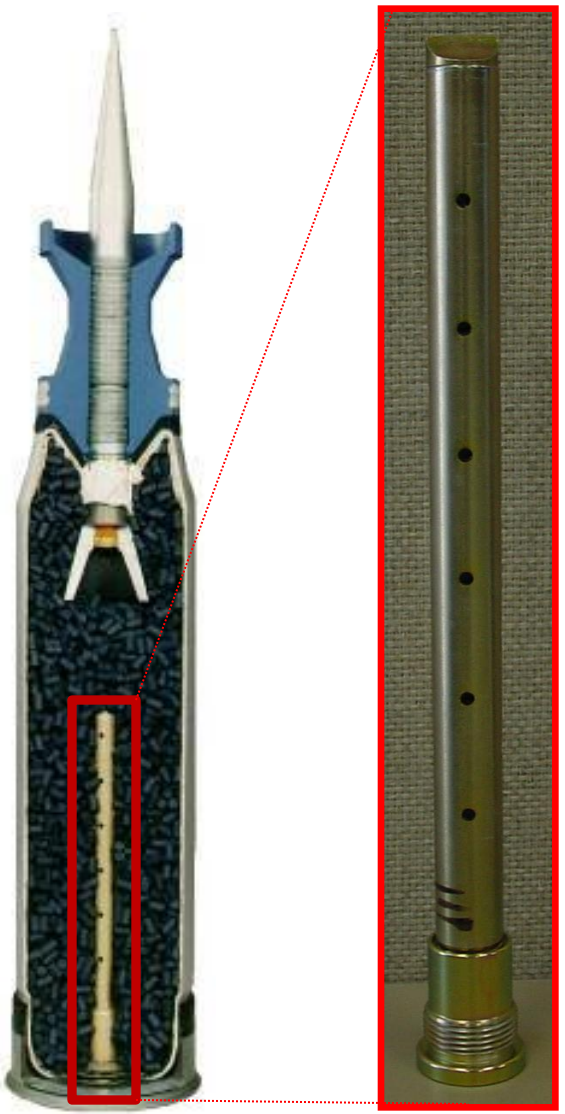
Presentation Outline

- Problem/Challenge
- Background
- Technical Approach
  - Cheetah Modeling of $BKNO_3$ combustion
  - Sensitivity Testing
  - Small Scale Performance
  - Adjustable Static Fire Test Fixture
    - Benite analysis
    - $BKNO_3$ powder analysis
- Conclusions/Future Work



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High Performance Igniter

Challenge:

- Create an igniter formulation that has:
  - **Excellent and consistent performance**
  - **Exhibits no flare back**
  - **Is more energetic than Benite.**
  - **Is less sensitive than Benite.**

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Mechanism of Igniter Action

- First step of Propellant ignition is endothermic.*
- Highly unstable products of this 1st step are reactants for the subsequent exothermic combustion reactions.
- Ignition of Nitrate Ester Propellants is self-propagating once surface temperature reaches 170°C.
- Raising surface temperature accomplished by use of igniters that transfer heat via two distinct processes.

- Convection
  - Gases generated travel across propellant surfaces at a high velocity and transfer their heat (energy) to the propellant.
  - Slow process.
  - Can be affected by propellant temperature.
- Conduction
  - Condensed Phase material.
  - Direct contact with propellant.
  - Can cause over ignition and the formation of pressure waves.

*R.A. Fifer; **S.A.** Uebman; **P.J.** Duff; K.O. Fickle; **M.A.** Schroeder. *Proceedings of the 22nd **JANNAF** Combustion Meeting*, **CPIA** Publication **432.** Vol. **II,** October, **1985.**

Technical Approach

- **Add commercially available ingredients to $BKNO_3$ to improve Oxygen Balance.**
- **Alter the Boron : KNO_3 ratio to improve Oxygen Balance**
- **Add various binders to $BKNO_3$.**
  - Will allow for extrusion of igniters into strands
  - Lower processing cost than pelletization.

$BKNO_3$

- Made of:
  - 70% Potassium Nitrate
  - 30% Boron
- Easily ignited at low **P**.
- High Gas Content
- Burn Rate insensitive to **P**.
- Hygroscopic (less than Black Powder)
- Flare Back (Incomplete oxidation)

Benite

- Made of:
  - 40% Nitrocellulose
  - 6.3% Sulfur
  - 44.3% Potassium Nitrate
  - 9.3% Charcoal
  - 0.5% Ethyl Centralite
- Performance as an igniter is adequate for tank applications.

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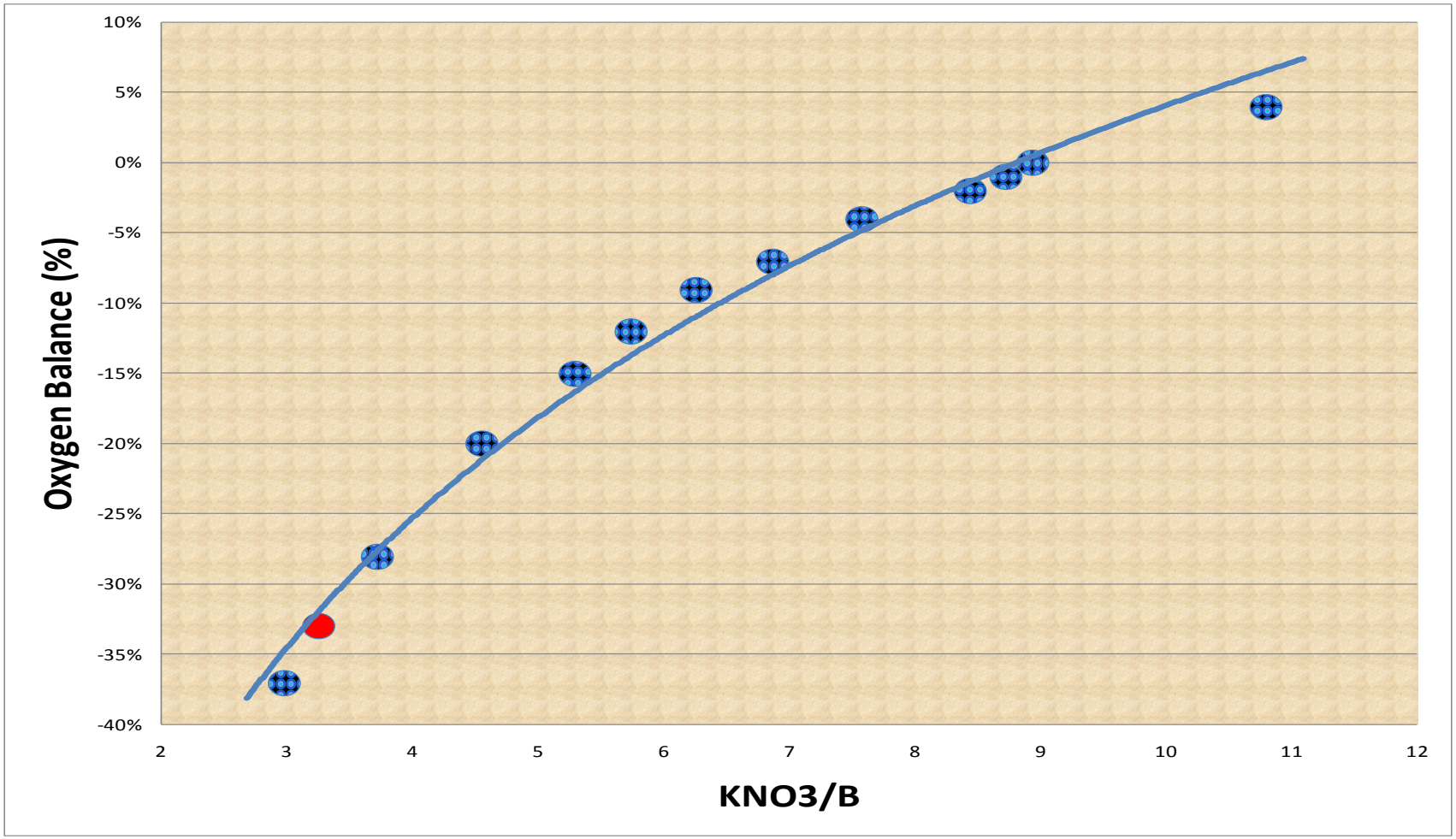
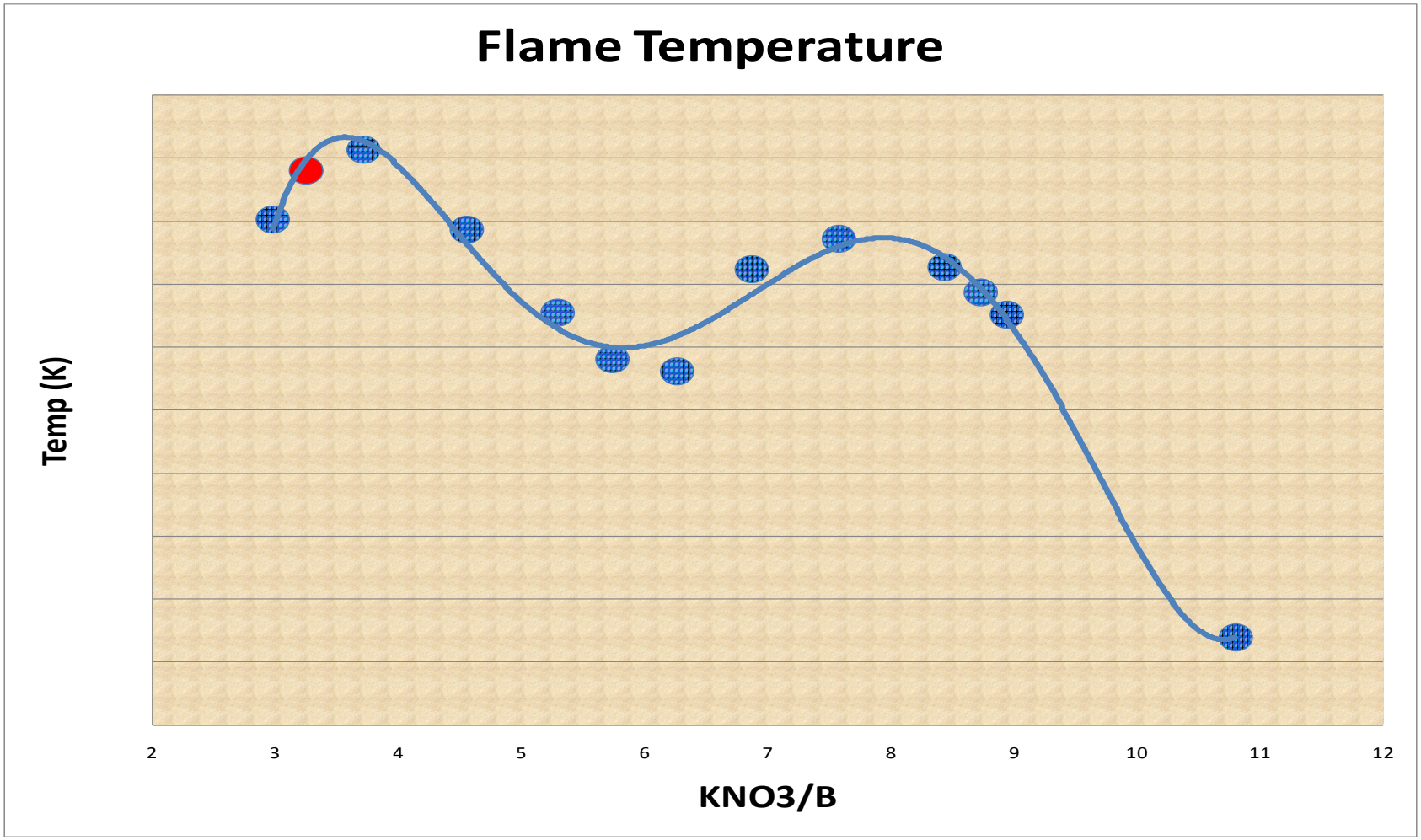
$BKNO_3$ Combustion: Oxygen Balance



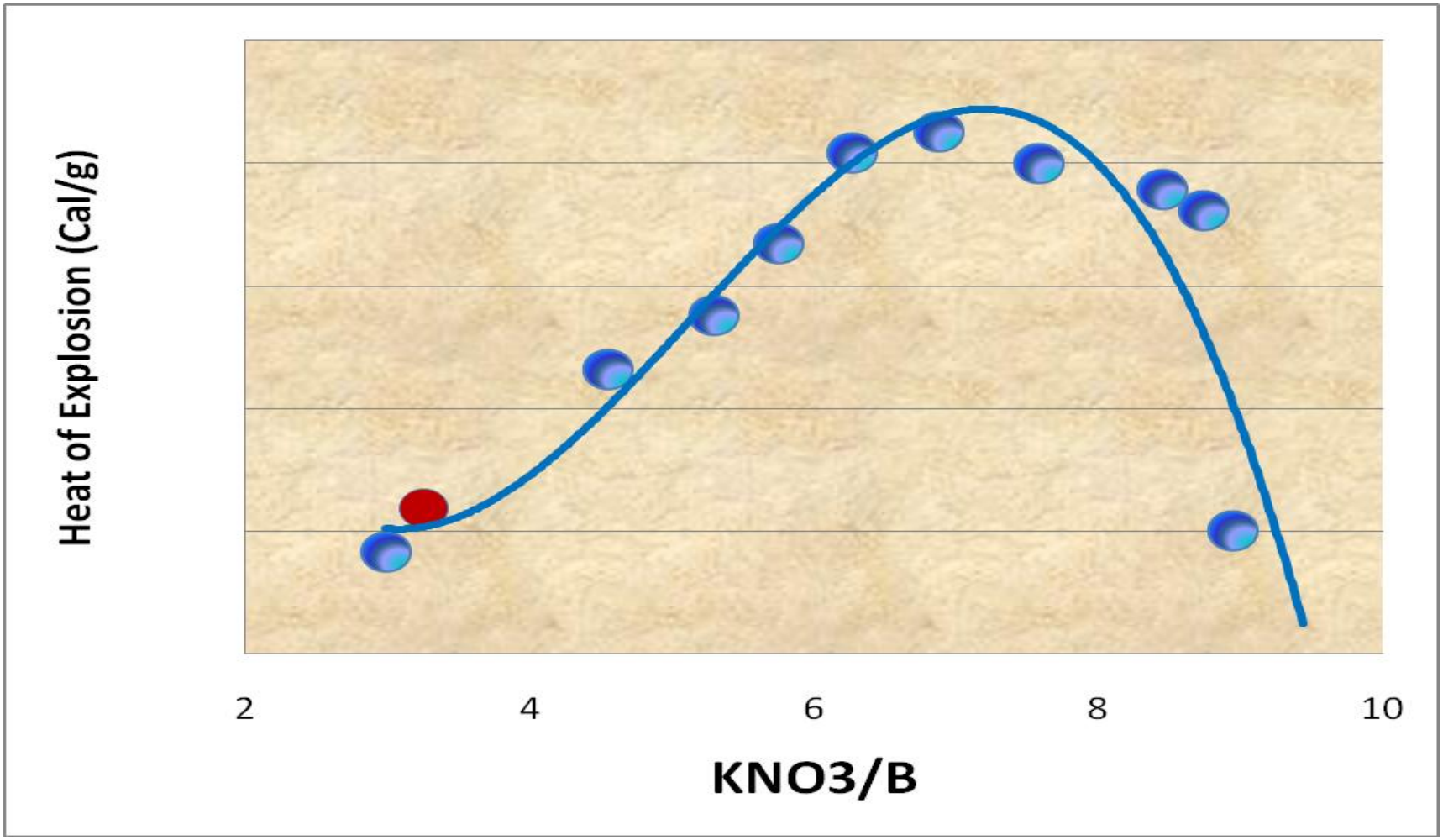
- Cheetah 5.0 modeling analysis

$BKNO_3$ Combustion: Flame Temperature



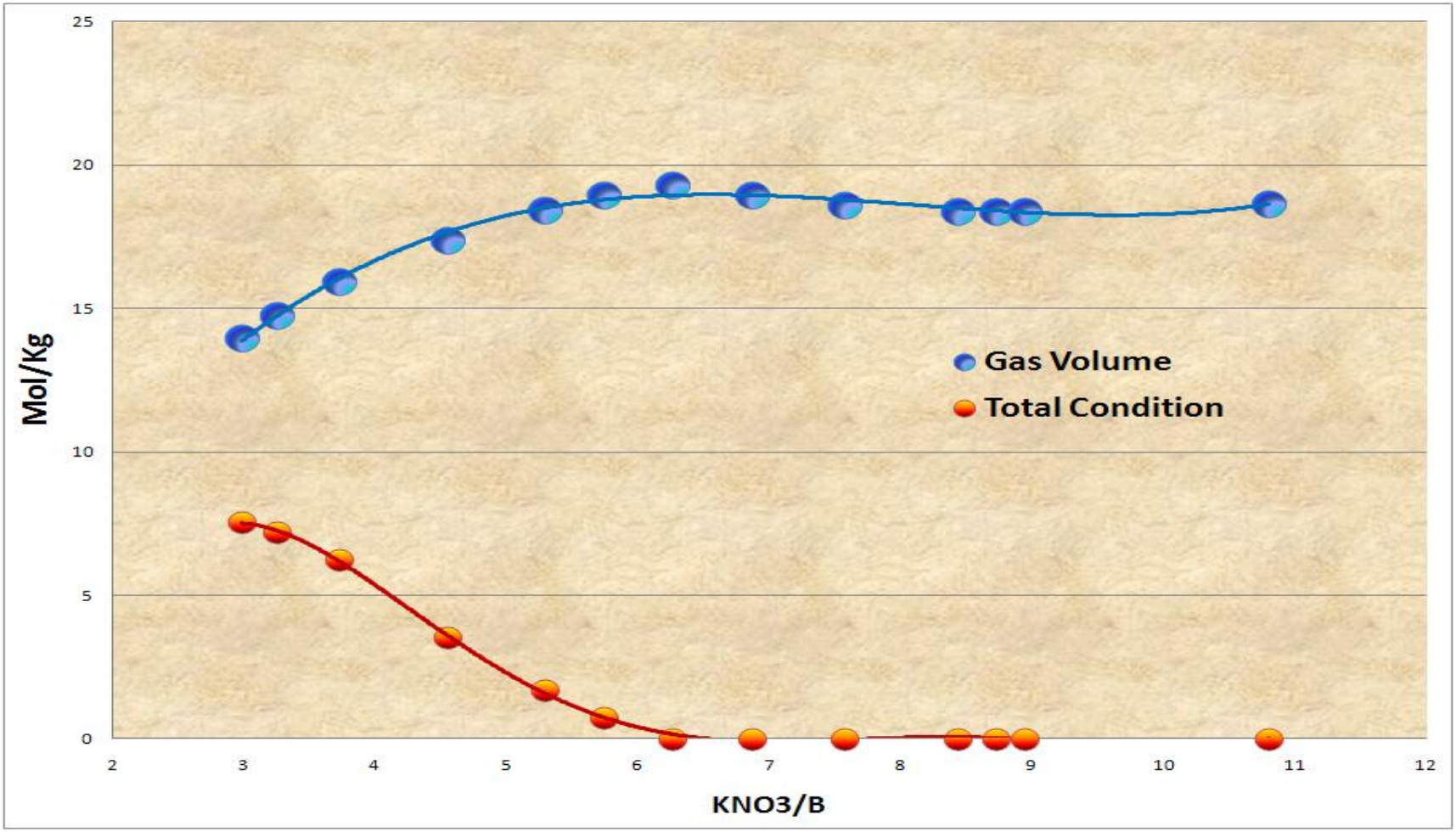
- Cheetah 5.0 modeling analysis

$BKNO_3$ Combustion: Heat of Explosion



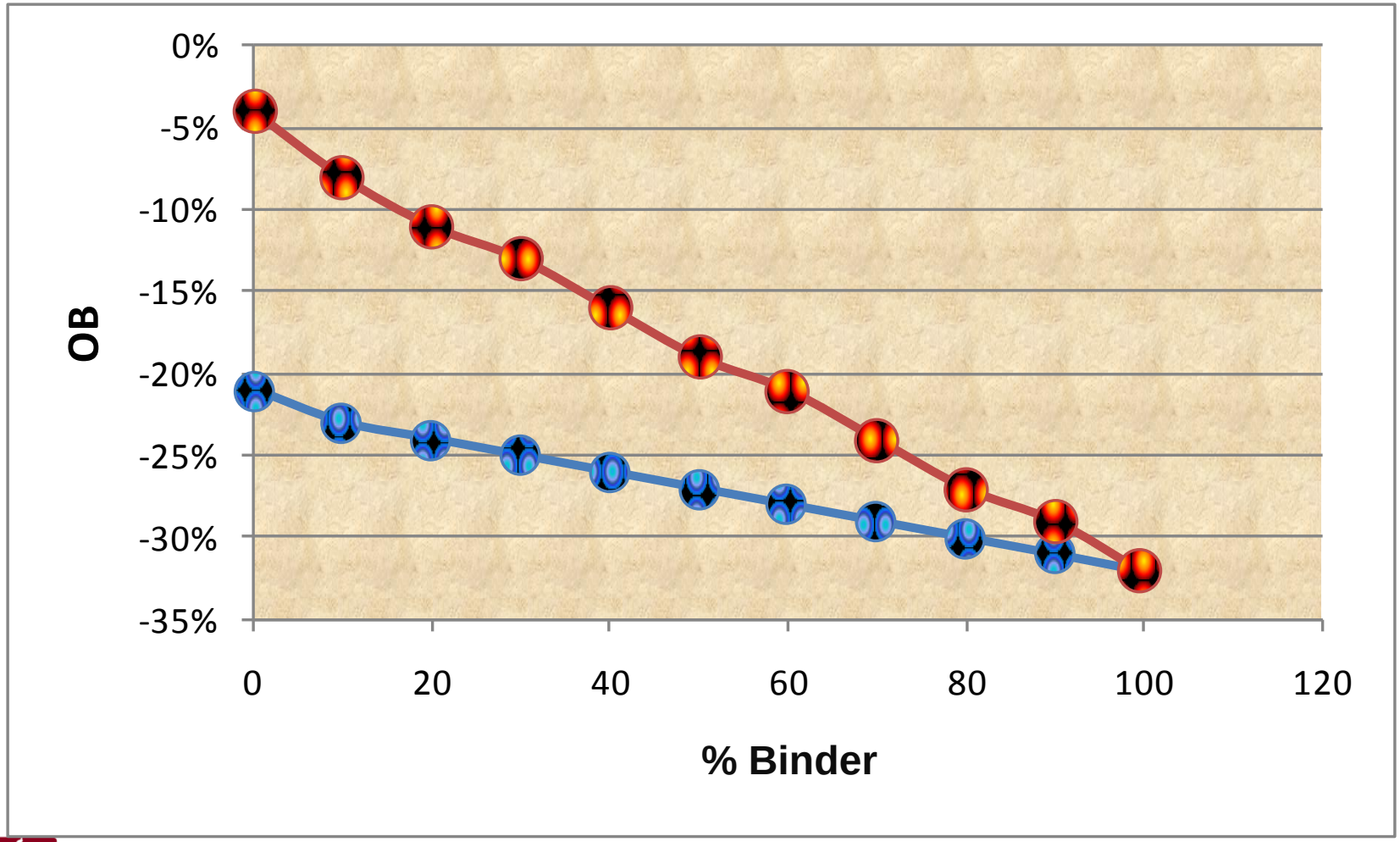
- MCVEPP modeling analysis

$BKNO_3$ Combustion Products



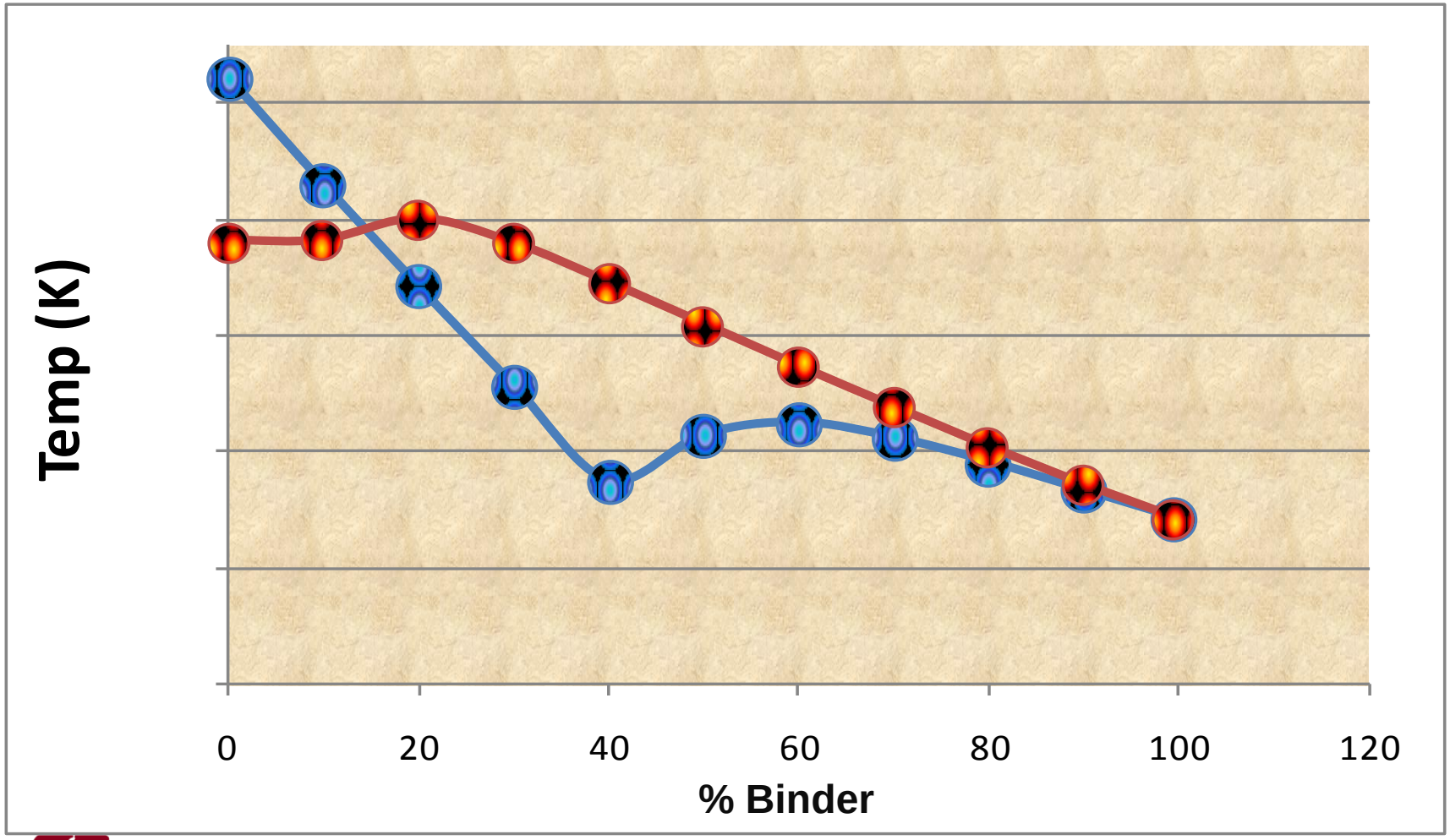
- Cheetah 5.0 modeling analysis

OB as a Function of Binder Content



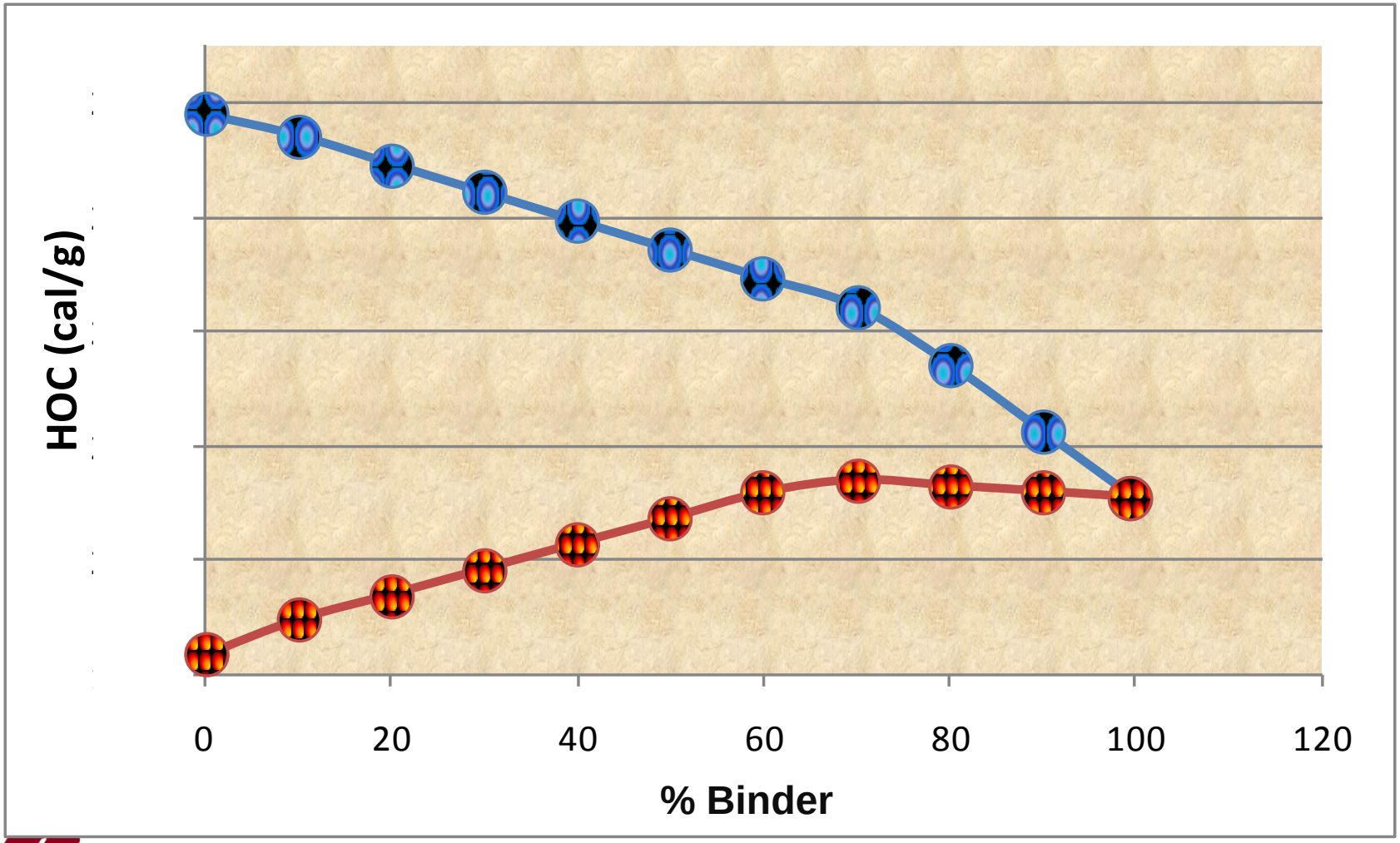
- Cheetah 5.0 modeling analysis

Flame Temp as a Function of Binder Content



- Cheetah 5.0 modeling analysis

Heat of Combustion as a Function of Binder Content



- Cheetah 5.0 modeling analysis

Predicted Performance of Initial Formulations

Formulation	Igniter Sensitivity			Predicted Performance		
	Impact ERL (cm)	BOE	Friction (GO / No GO) (N)	Impetus (J/g)	Flame Temp (C)	HOE (cal/g)
Benite	18.8	6 of 10	288 / 252	488	2361	824
$BKNO_3$	23.2	10 of 10	> 360	419	3603	580
PAI-8552	>100	0 of 10	240 / 216	739	3313	401
PAI-8553	>100	0 of 10	240 / 216	710	3285	413
PAI-8550	16.8	10 of 10	168 / 144	738	3427	802
PAI-8554	22.3	10 of 10	288 / 252	595	3211	517
PAI-8555	18.9	9 of 10	288 / 252	679	2727	696
PAI-8556	22.4	7 of 10	240 / 216	613	2720	641
PAI-8557	24.6	5 of 10	324 / 288	594	2224	540
PAI-8558	>100	0 of 10	252 / 240	481	2018	360

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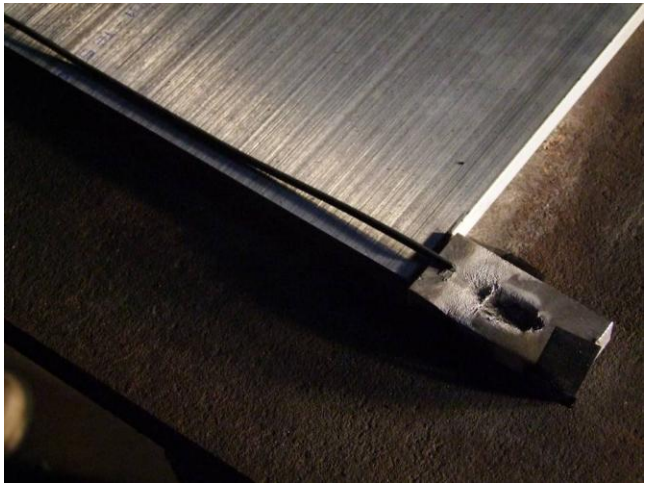
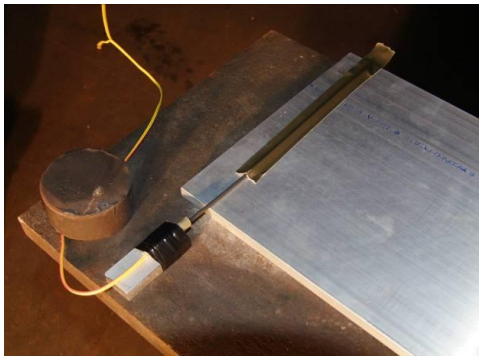
Table 1: Critical Diameter results

Critical Diameter Testing

Critical Diameter

Lot #	Diameter	Result
8551	0.1345	NOGO
8551	0.1350	NOGO
8558	0.1405	NOGO
8558	0.1415	NOGO
8556	0.1420	NOGO
8556	0.1440	NOGO
8557-3	0.1400	NOGO
8557-3	0.1385	NOGO





Thermal Stability

Material	Starting Weight	Total Loss	Pass - Fail
PAI 8556	50.4135gms	.1464gms	PASS
PAI 8557	50.2485gms	.2614gms	PASS
PAI 8558	50.2745gms	.1545gms	PASS

Small Scale Burn

Material	Burn Time	Explosion	Detonation	Pass/ Fail
PAI-8556	Less 1 Sec.	NO	NO	Pass
	Less 1 Sec.	NO	NO	Pass
	Less 1 Sec.	NO	NO	Pass
PAI-8557	Less 1 Sec.	NO	NO	Pass
	Less 1 Sec.	NO	NO	Pass
	Less 1 Sec.	NO	NO	Pass
PAI-8558	2.01 Sec.	NO	NO	Pass
	2.79 Sec.	NO	NO	Pass
	3.05 Sec.	NO	NO	Pass

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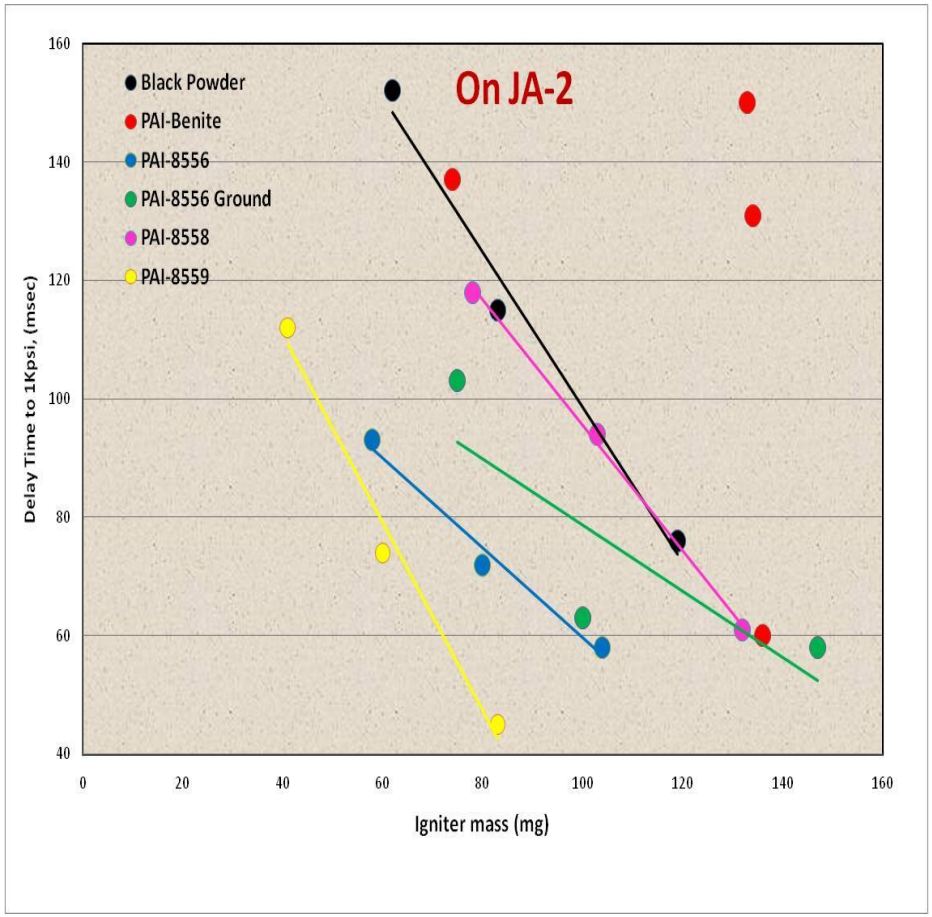
Subscale Performance Analysis



- BP & PAI-8558 behave very similarly.
- PAI-Benite very erratic behavior.
- BP, PAI-8558, & PAI-8559 are very sensitive to their mass (large negative slopes)
  - BP & CAB containing Igniters

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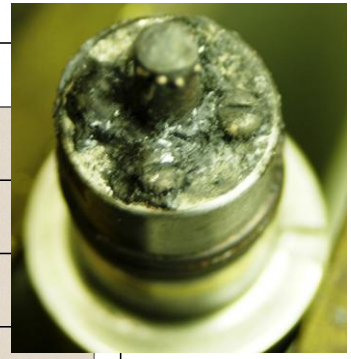
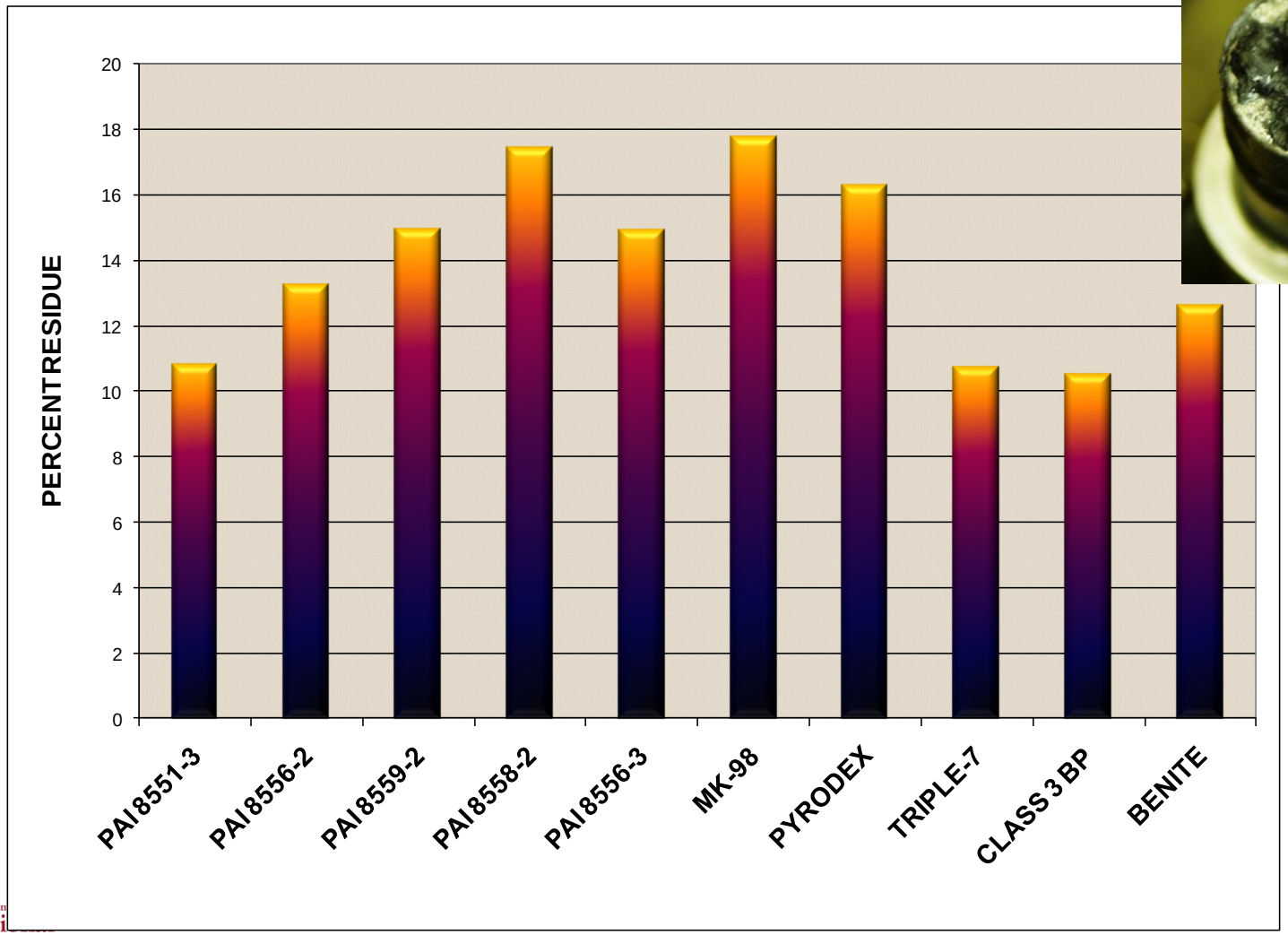
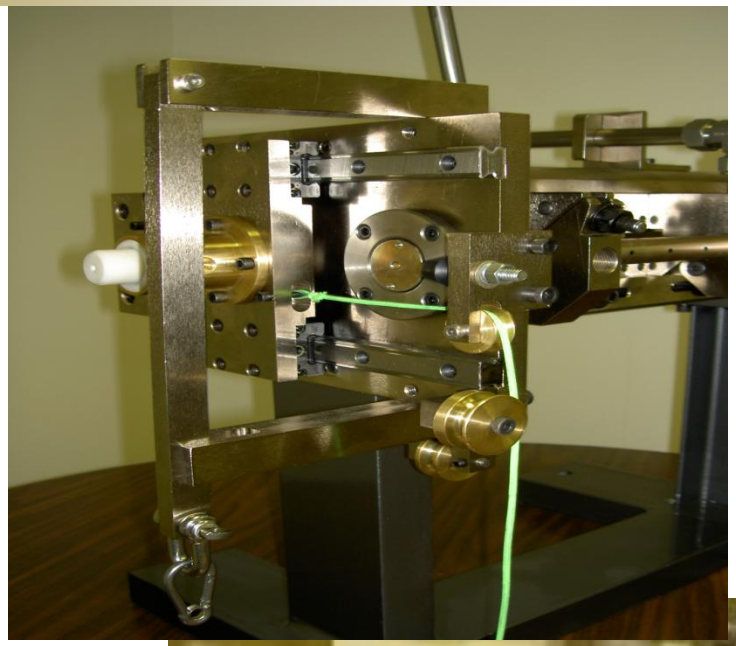
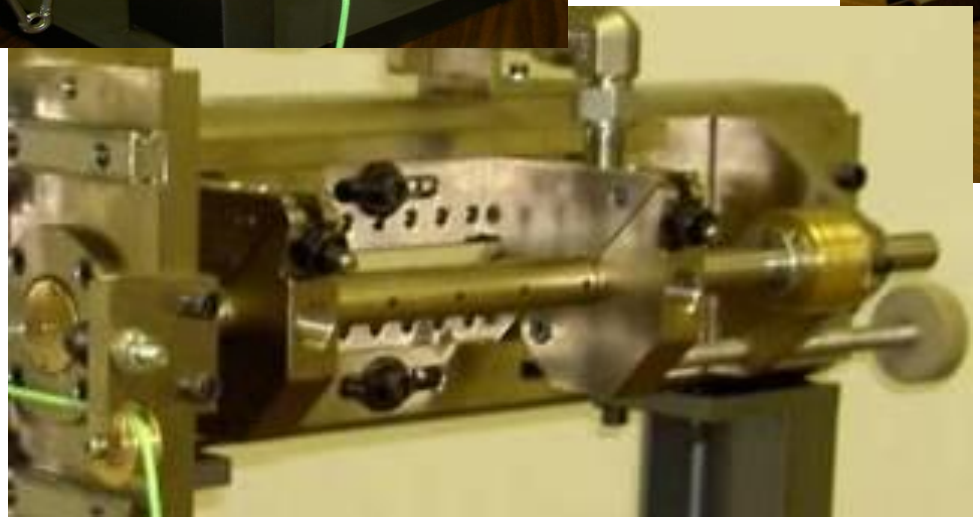
Residue Concerns



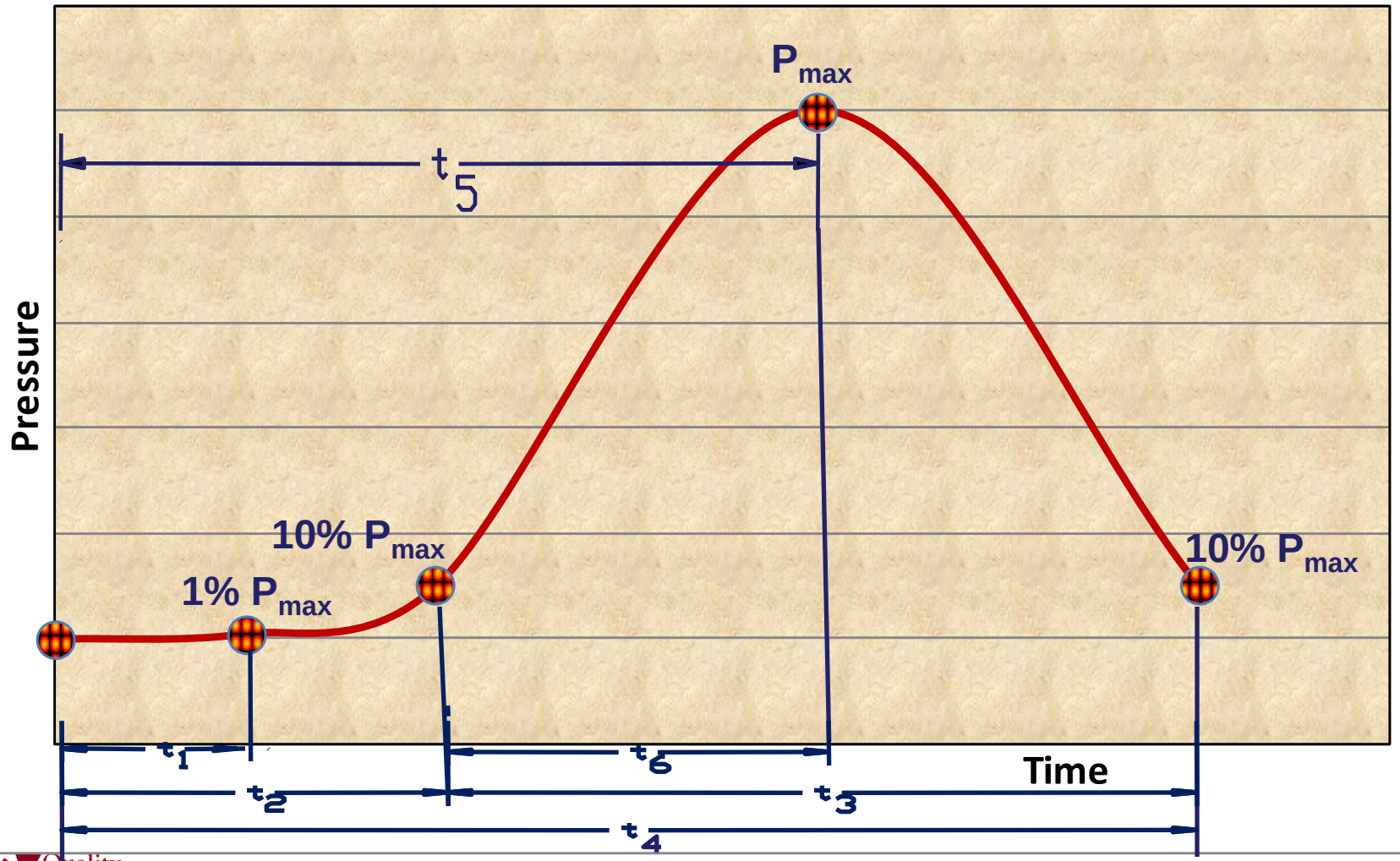


Static Igniter Test Fixture

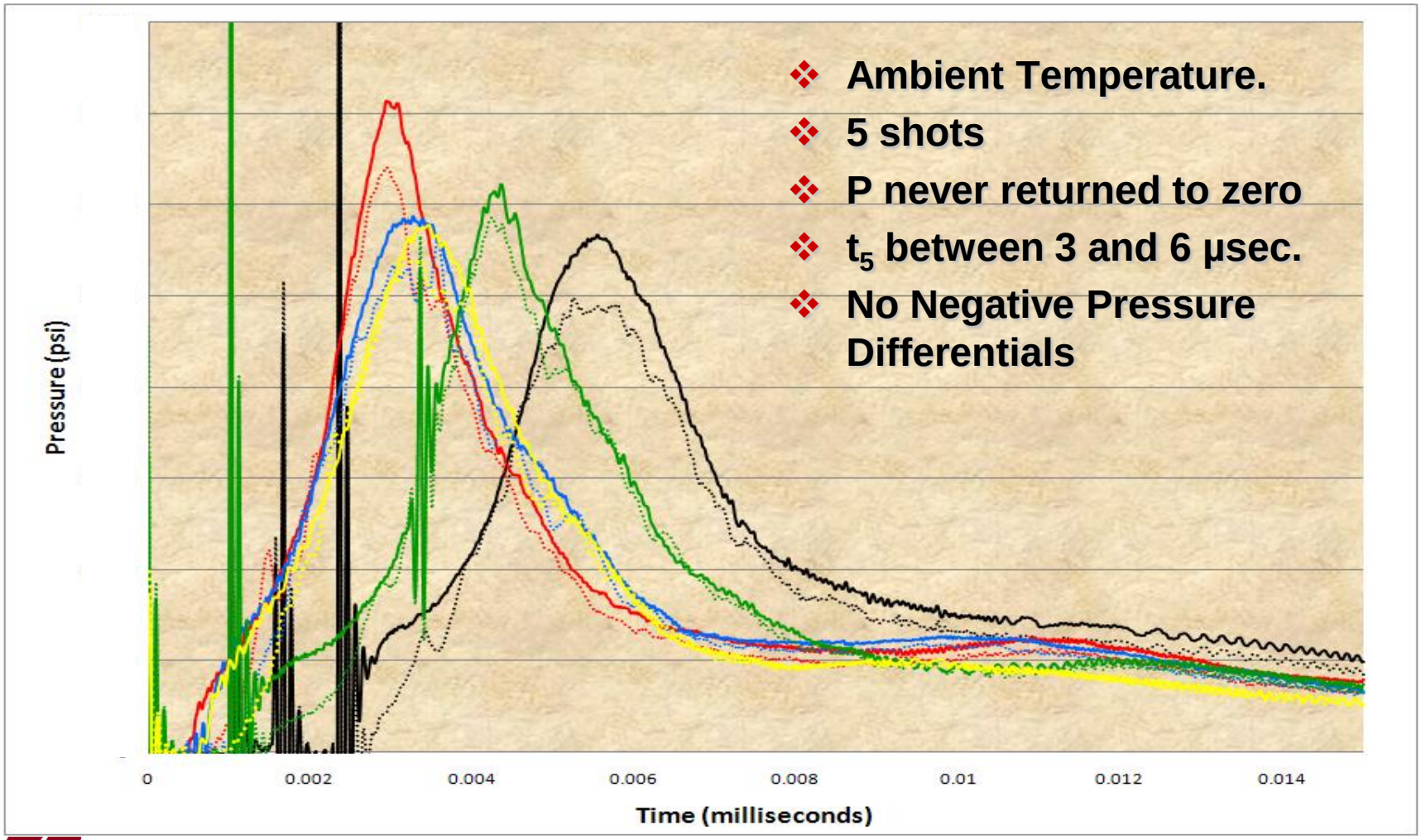




Expected Data



Benite at Ambient Temperature



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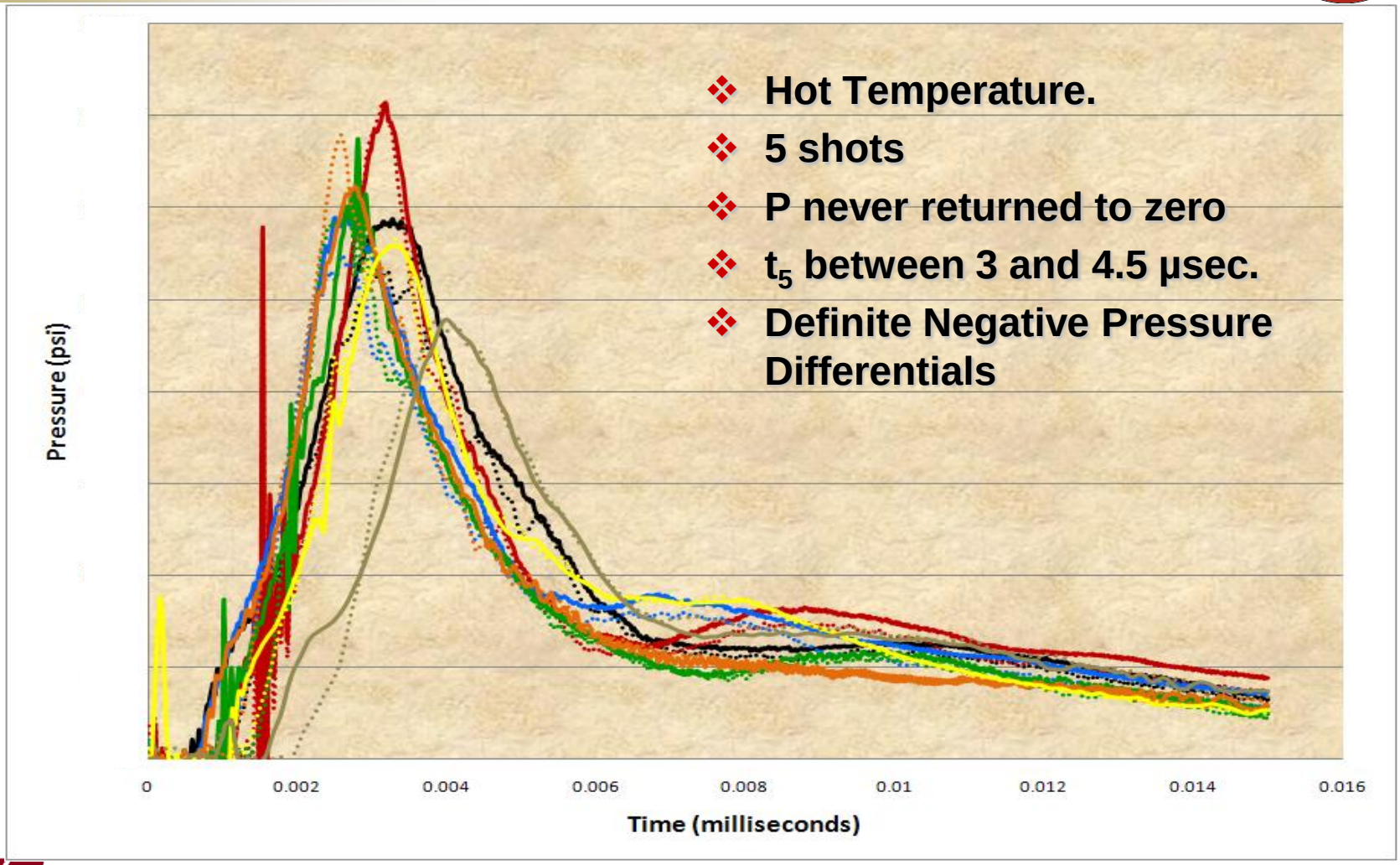
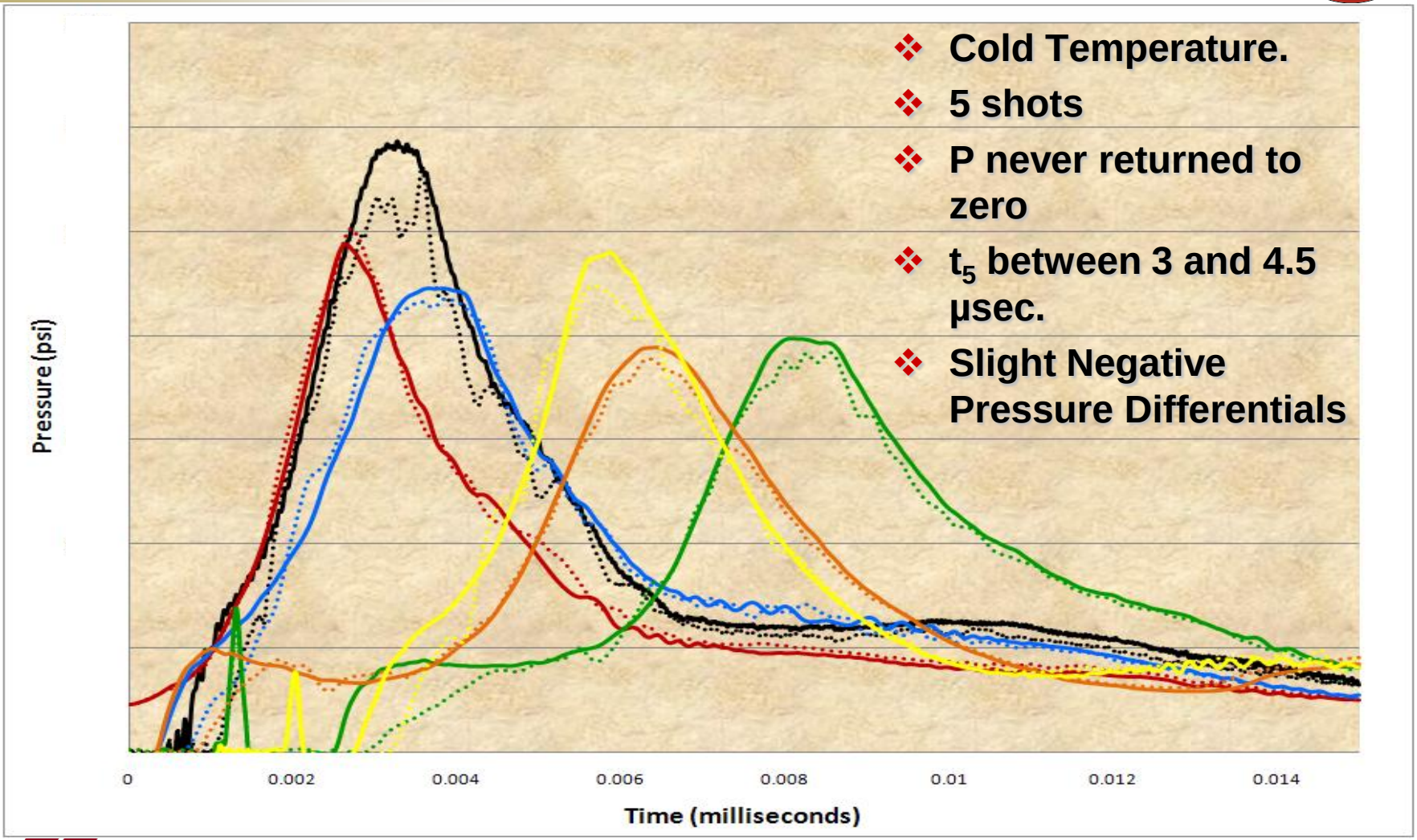
Benite at 63ºC



- Hot Temperature.
- 5 shots
- P never returned to zero
- t_5 between 3 and 4.5 µsec.
- Definite Negative Pressure Differentials

Benite at -32°C



- Cold Temperature.
- 5 shots
- P never returned to zero
- t_5 between 3 and 4.5 µsec.
- Slight Negative Pressure Differentials

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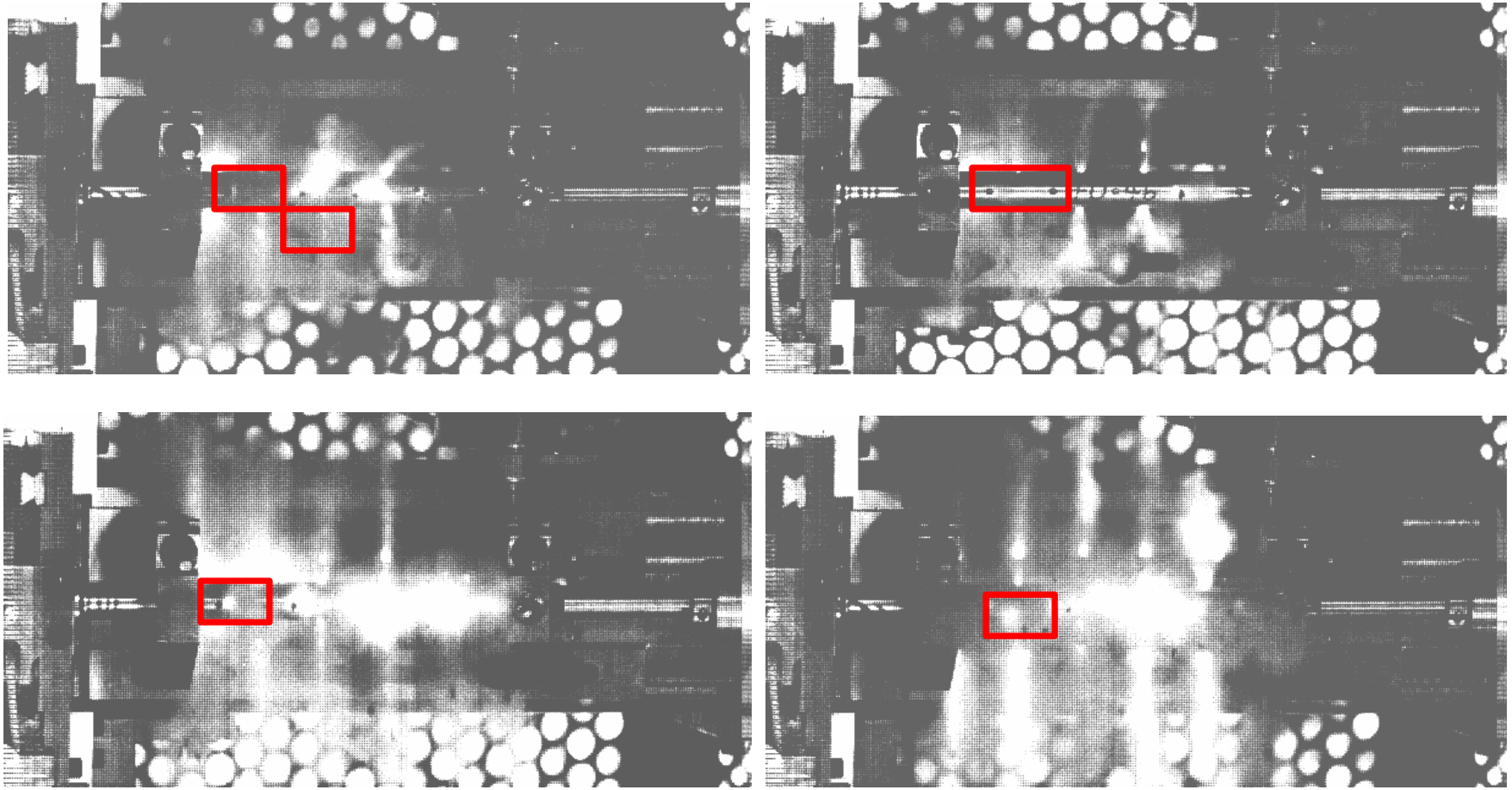
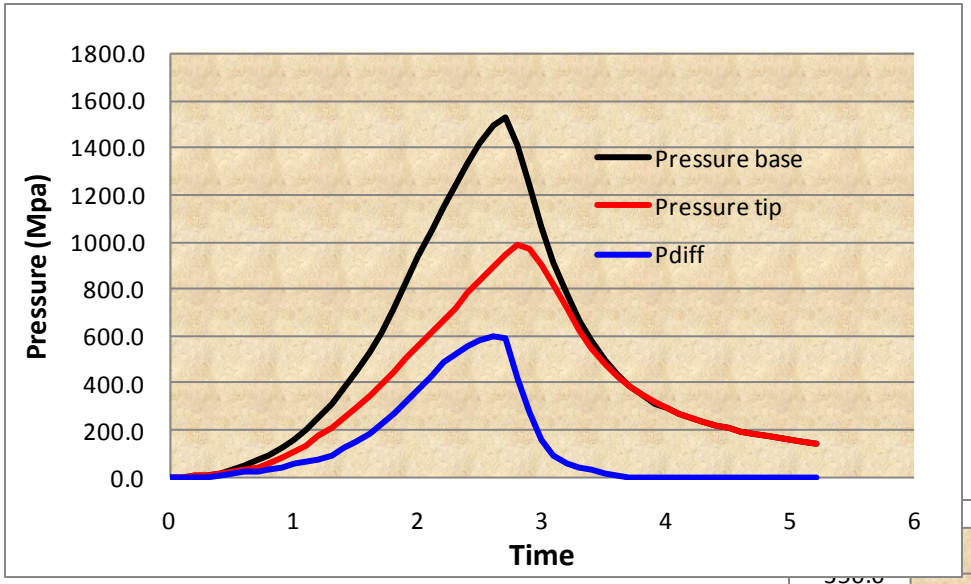
High Speed Video Stills of Benite Igniter at Ambient Temperature

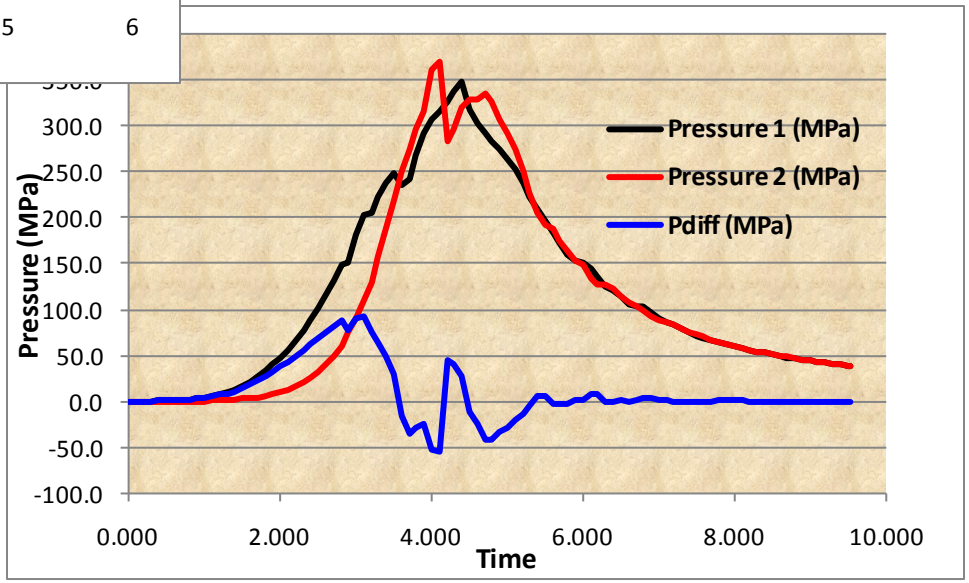


FNGUN Analysis



- Instantaneous Ignition along the igniter tube.
- No Pressure Differentials.

- Staged Ignition from the middle of the igniter tube.
- -50 MPa Pressure Differentials.



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Summary/Conclusions

- PAI-8556, 8557, and 8558 demonstrated excellent performance and reduced sensitivity characteristics.
- An adjustable igniter static test fire fixture was designed, built, and tested.
  - Benite was examined in this fixture and found to have significant shot to shot variability in terms of pressure and time, except at hot temperatures.
  - When $BKNO_3$ unsieved powder was examined in this fixture, it exhibited very consistent ignition delay and rise times, but did demonstrate the formation of pressure waves.
- Combustion of $BKNO_3$ was found to be very reliant upon oxygen balance, which itself is dependent upon the ratio of fuel to oxidizer.
- $BKNO_3$ analogues containing binder and other combustion enhancing additives were examined for their thermo-chemical properties and have been produced.

Future Work

- Other commercially available $BKNO_3$ grains/pellets, namely IB, IIC, and IE, will be examined in the fixture.
- Convert the 125mm electrical igniter fixture to accept 105mm percussion ignition primers.
- The igniters that have been produced will be tested for their performance and further optimization of the formulations will be performed.
- Once the effects of the additives are ascertained, they will be employed in $BKNO_3$ analogues that do not employ any binder, and will be pelletized.
- PAI-8558 and PAI-8557 formulations are awaiting performance analysis in the Navy 40mm gun as well as fragment impact testing.
- To improve Benite's sensitivity, several formulations are being examined where the Binder is replaced with a more IM compliant binder.

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