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An Approach to Simulate the Cook-off Response of Large Scale Munitions Using Small Scale Tests and Analysis

By

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Presented at

Insensitive Munitions and Energetic Materials Technology Symposium
09/12/2016 – 09/15/2016
Nashville, TN

Performed under STTR Topic N10A-T011, Contract N68335-12-C-0006

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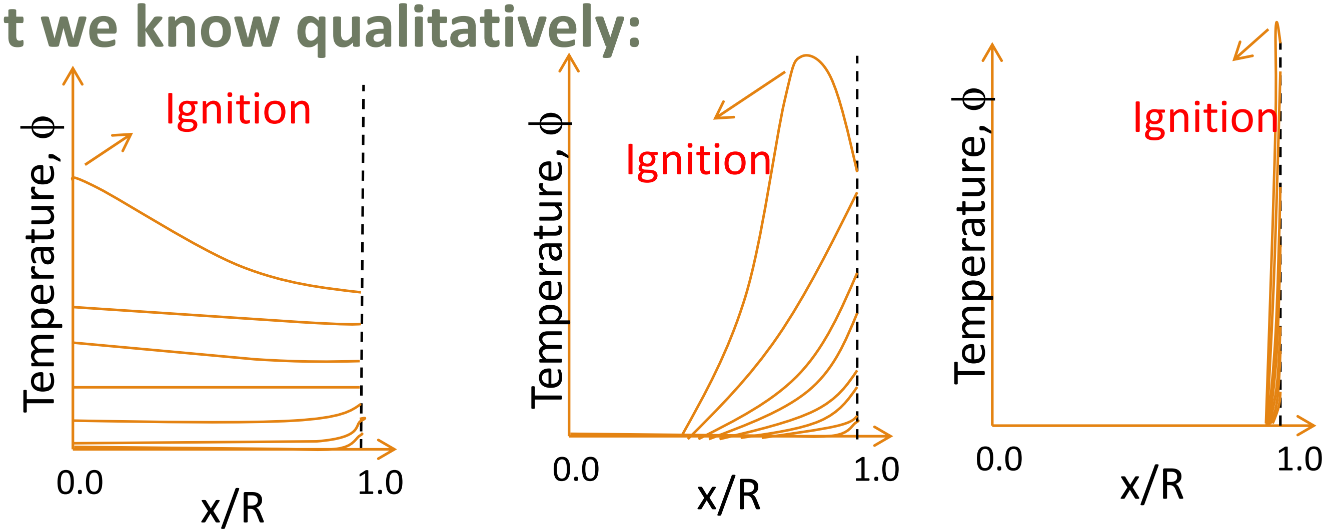
Background – Effect of Scale and Heating Rate on Cook-off

What we know qualitatively:

SCO



FCO

Small Propellant
Slow Heating Rate
→
Large Propellant
Fast Heating Rate

More % material involved ← Less % material involved

What is missing quantitatively:

1. Extent of thermal degradation prior to ignition
2. Effect of thermal degradation prior to ignition on burn rate and violence

BlazeTech Approach/Talk Outline

1. Thermal degradation tests → kinetics rates as f(Temperature- time)
   - Confined and unconfined samples
   - Tracked pressure and its effects on degradation
2. Burn rate tests on pristine and degraded samples → $u_{burn} = A \times P^n$
   - Dependence of A and n on degraded state
3. Cook-off models using heat conduction + 1 and 2
4. Small scale cook-off tests and compare results to model predictions
5. Use data from literature to validate model and investigate tradeoffs between scale and heating rate
   - Compared wall temperature at ignition ($T_{wall@ignition}$) for both small and large scale tests
   - Focus on PBXN-109 for which there is data in literature at different scales

1. Thermal Degradation of Confined Samples Prior to Ignition

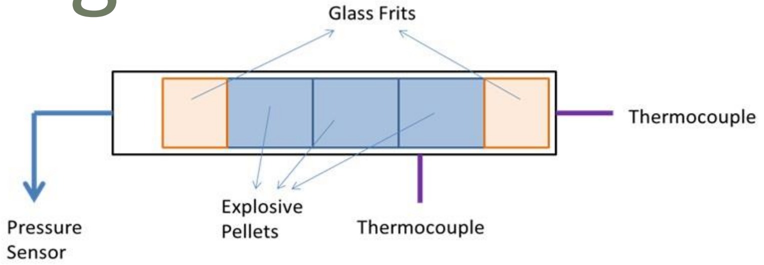
Three ¼”×¼” cylindrical pellets per test

Heat to T for finite duration to induce thermal degradation. Test stopped before cookoff.

Measurements

- P(t) and T(t) during the test
- Sample mass before and after test
- Account for amount of gas formation and condensation

Model development for thermal degradation kinetics



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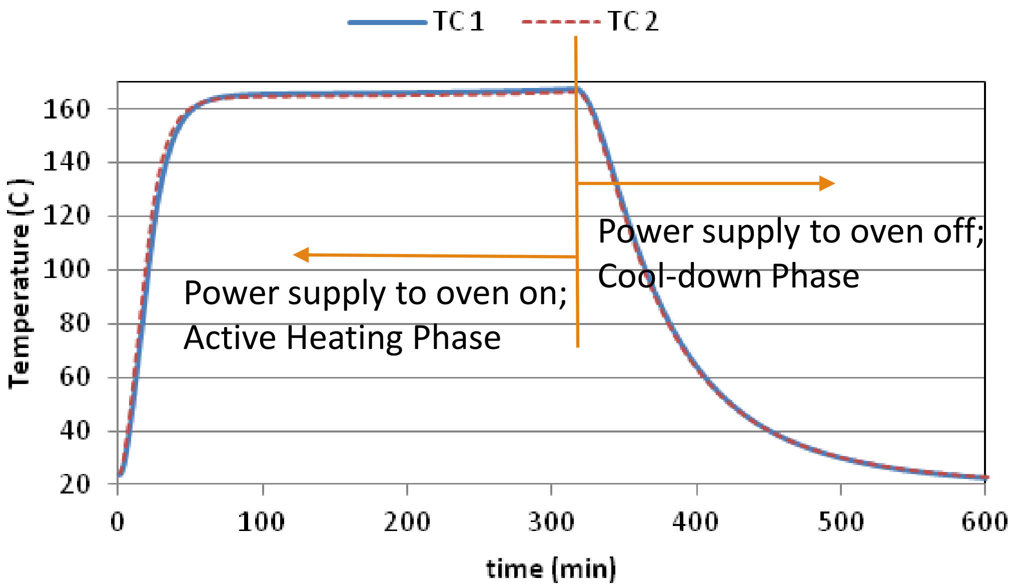
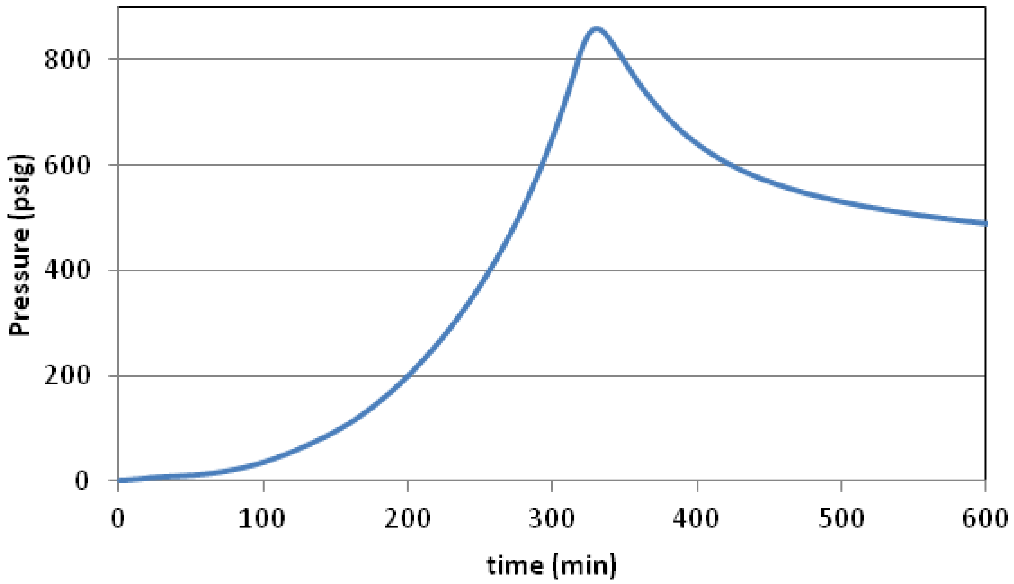
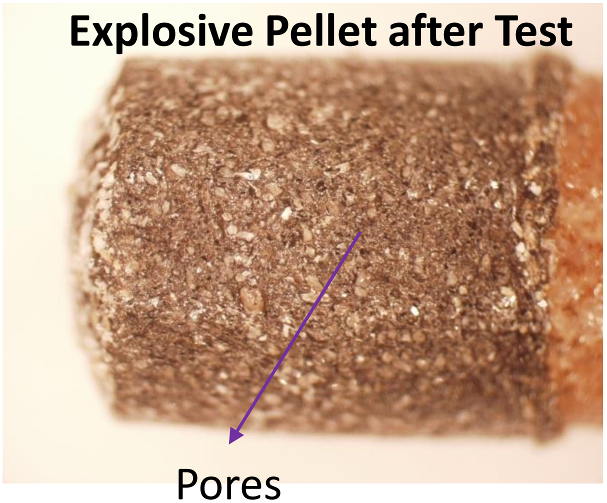
Sample Test with PBXN-109

- Duration for which the sample remains above 130°C ~ 317 min
- Mean Temp. for the above duration ~ 163.4 °C





High Resolution Image of Explosive Pellet after Test



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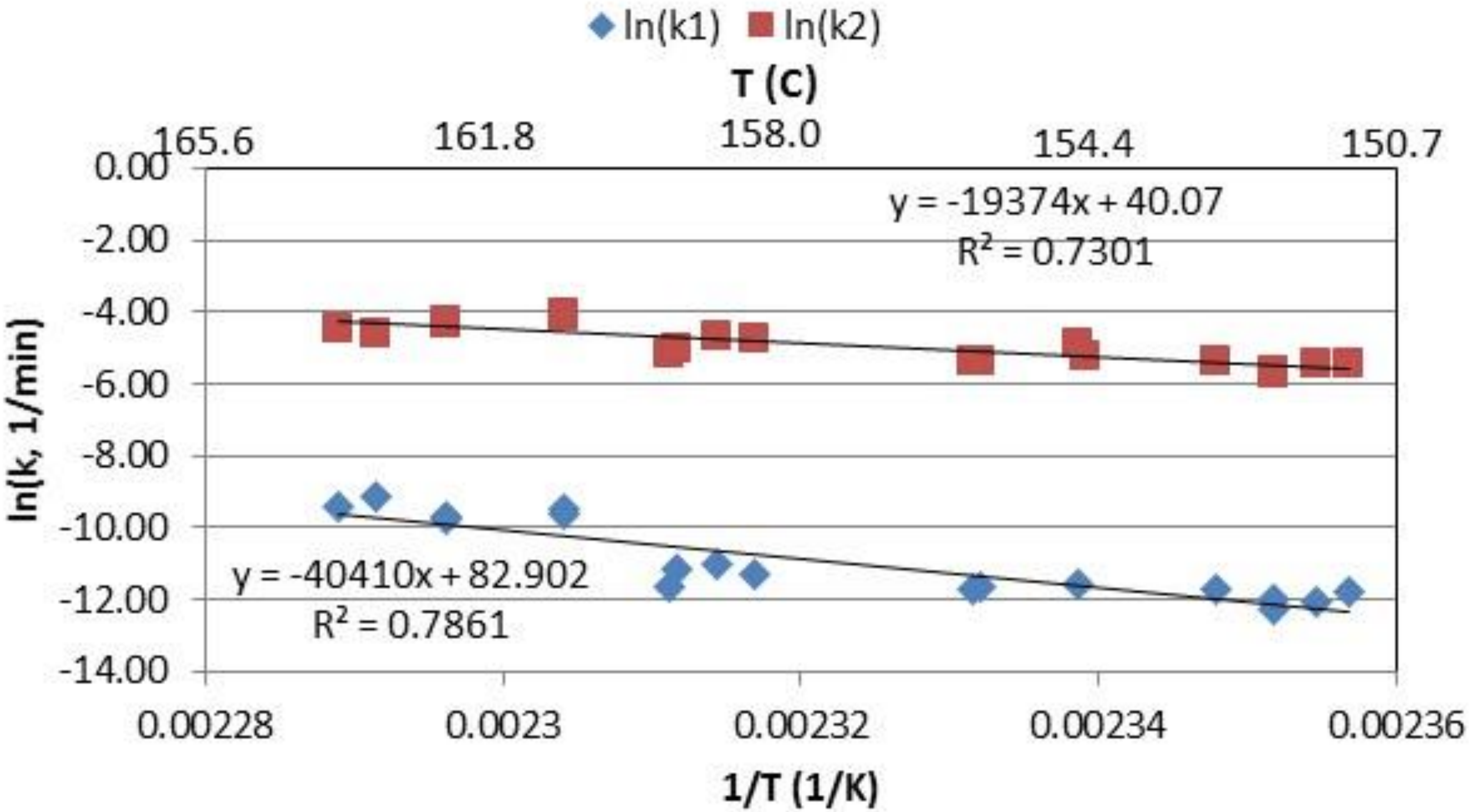
PBXN-109 Thermal Degradation Kinetics



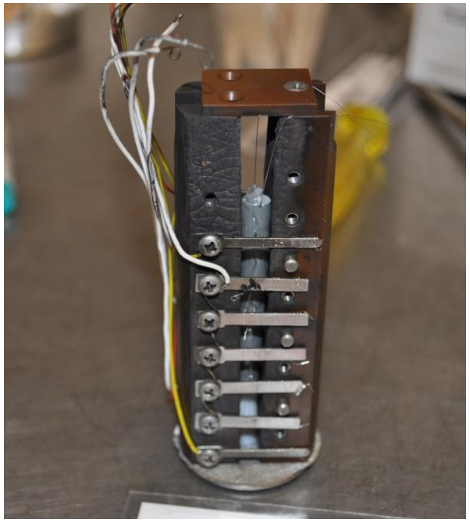
- Fitted a two-step first order reaction model to the test data
- Reaction rate constants (k_1 and k_2) depend only on T

2. Burn Rate of Thermally Degraded Explosives in a Confined Strand Burner

- TC & break-wires between pellets
- Pressure adjusted to the target level
- Expose strand to desired T(t)
- Then ignite top end of strand
- Measure P(t), T(t), u_{burn}(t)
- Fit data to classical power law:

$$u_{burn} = A \times P^n$$

- A depends on extent of thermal degradation prior to ignition; n=constant



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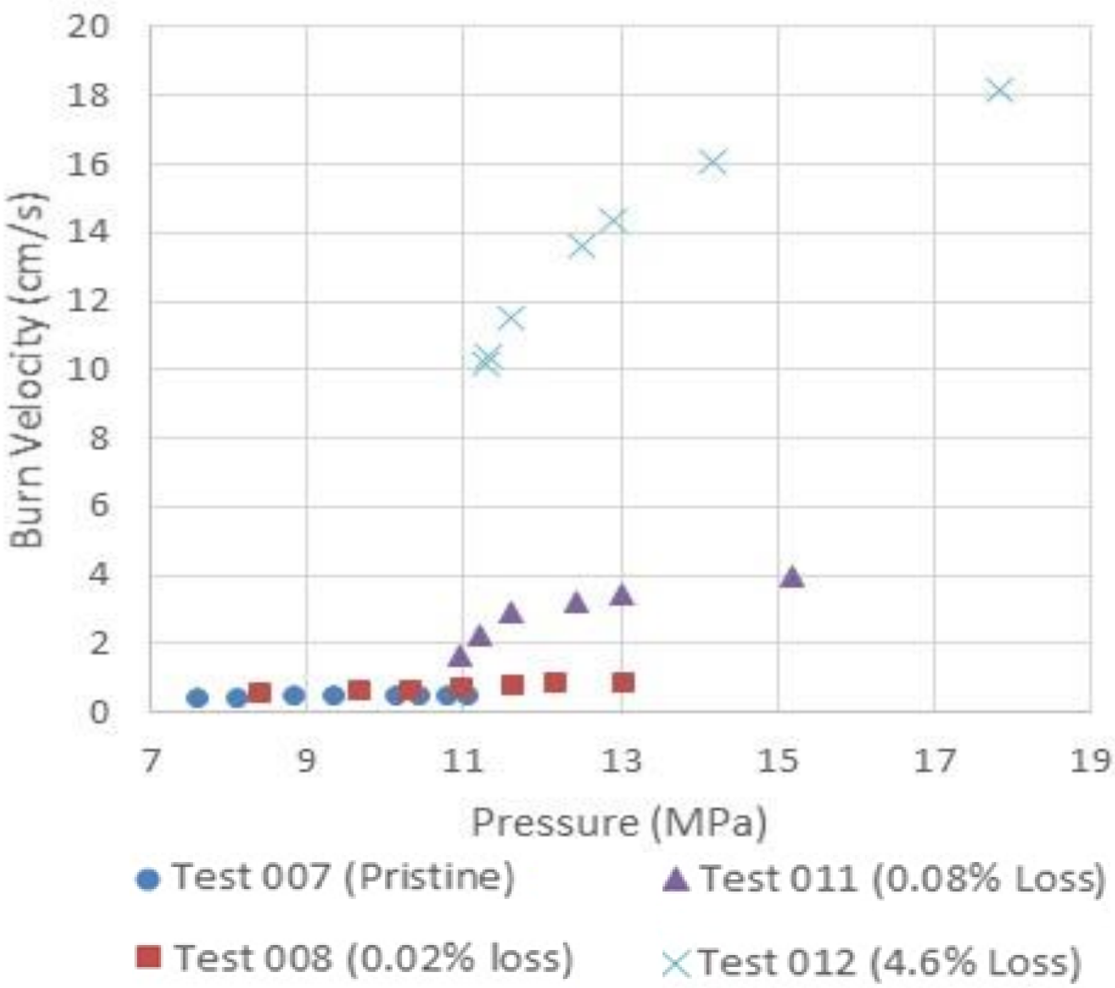
Measured Burn Velocities vs. Pressure and Extent of Thermal Degradation



3. BlazeTech Cook-off Model

Fast running 1-d model, includes

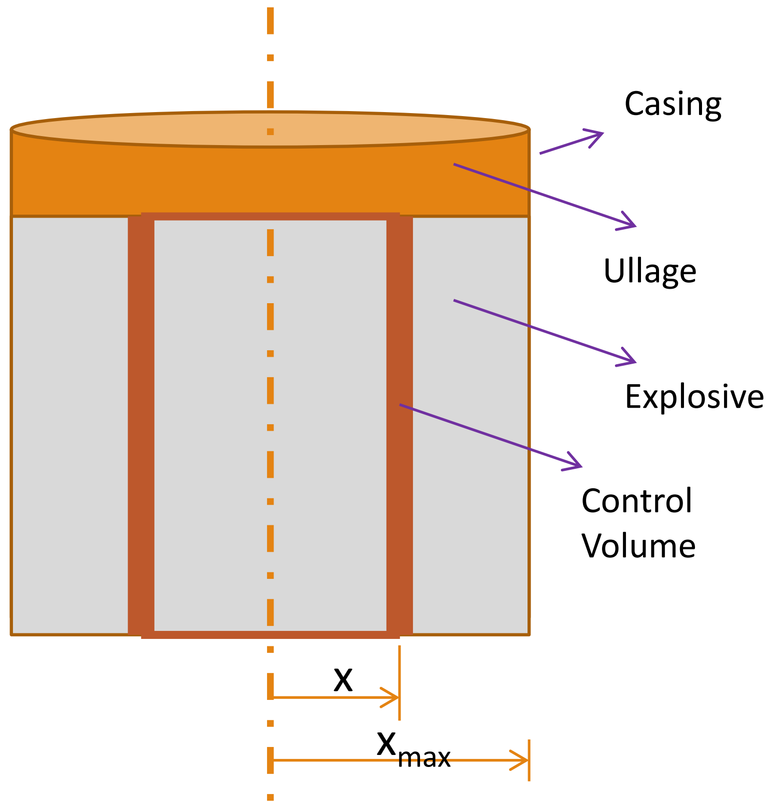
- Rapid heating from $T_{ambient}$ to T_{soak}
- Soak for finite duration T_{soak}
- Slow heating from T_{soak} to ignition

Model tracks

- Heat conduction, thermal expansion and phase change
- Chemical reactions
  - Pressure rise due to heat and gas release
  - Mass loss and increase in porosity
- Ignition when temp. inside the explosive >> wall temp.

Model outputs:

- T(x), residual explosive mass, reaction conversion, specific surface area vs. time
- Occurrence of ignition and its location
- Burn rate
- Casing pressure time history (which is indicative of violence)



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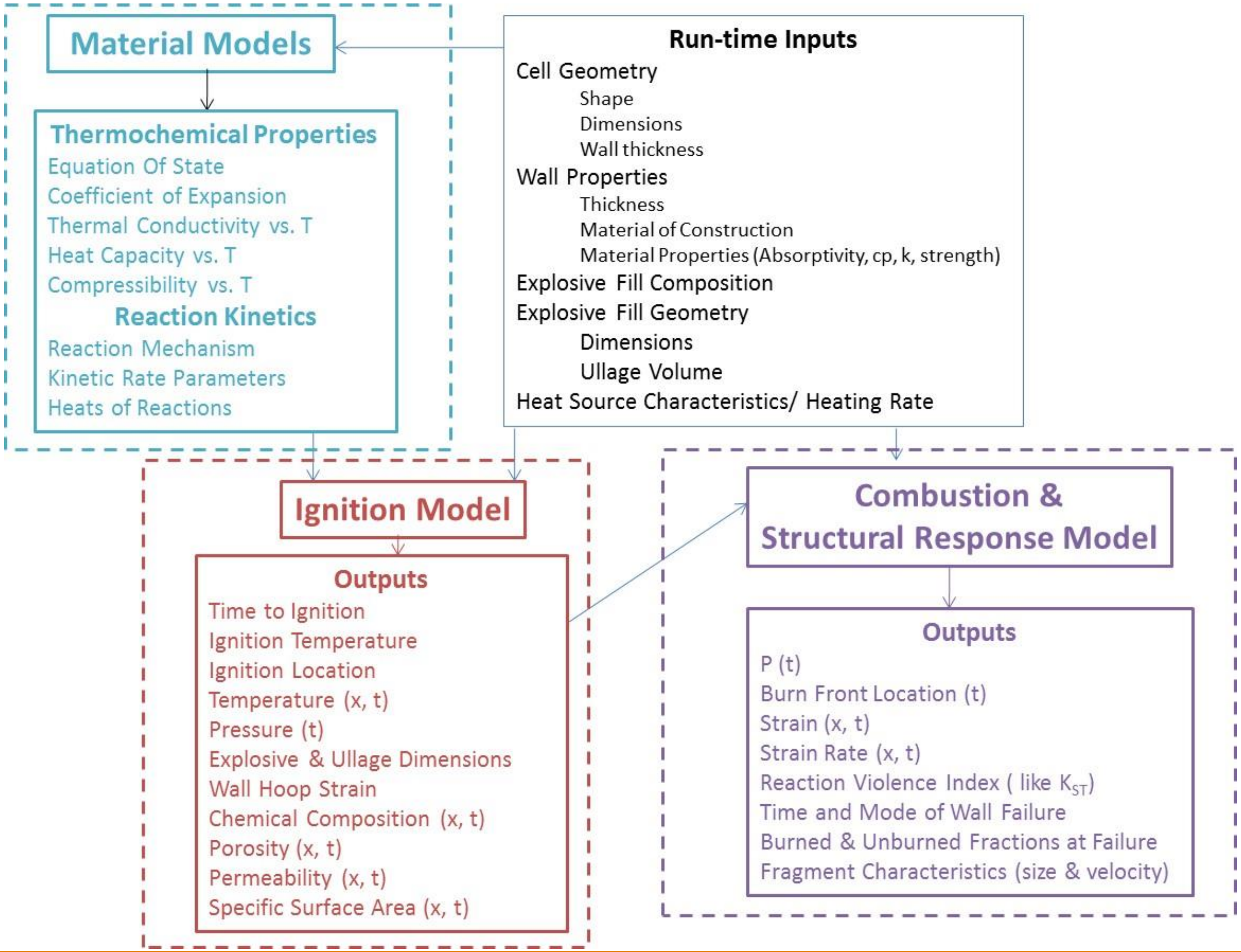
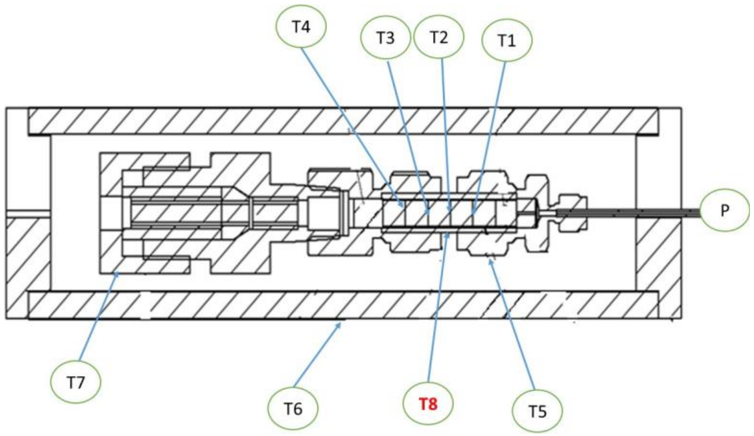
Unified Model for SCO and FCO

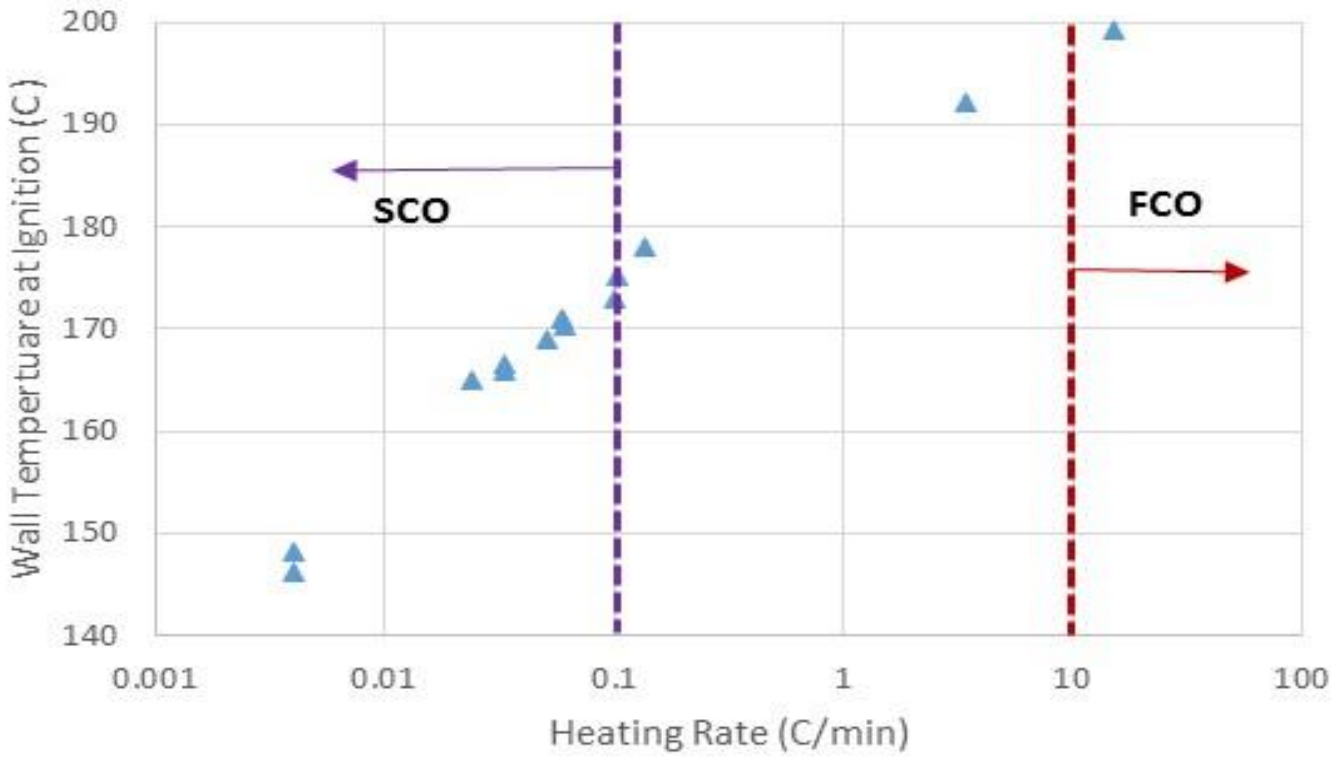


4. Small-scale Cook-off Tests



5 pellets, ¼ inch, 1.7 grams
16 SCO tests on confined PBXN-109 pellets varying heating rate from 0.004 C/min to 15 C/min

Measured $T_{wall@ignition}$ in BlazeTech Tests



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5. Literature data for Model Comparison

Parameter	Description	Literature data with increasing test article size				
Container Dimensions	Length (cm)	12.10	12.12	21.37	45.21	155
	Inner Diameter (cm)	2.06	2.07	5.08	17.78	25.5
	Wall Thickness (cm)	0.22	0.22	0.4	1.25	1.2
Explosive	Mass (g)	57.38	58.44	679	15150	84,000
	Volume (cm^3)	34.36	34.99	407	9072	50,250
	Length (cm)	10.3	10.35	20.3	42.95	137
	Diameter (cm)	2.06	2.07	5.08	17.78	25.5
	Ullage Volume (%)	14.9	14.6	5	5	10
Heating Profile	Initial Heating Rate (°C/min)	10	15	10	3.3	NA
	Soak Temperature (°C)	130	155	130	147.2	42
	Soak Duration (min)	20	30	300	300	NA
	Final Ramp Rate (°C/min)	0.1	0.05	0.0167	0.05	0.056
Results	$T_{wall@Ignition}$ (°C)	174±1	169.5±1	152	164	~ 166.7
	Time to Ignition After Soak (min)	442	295	1320	354	2244

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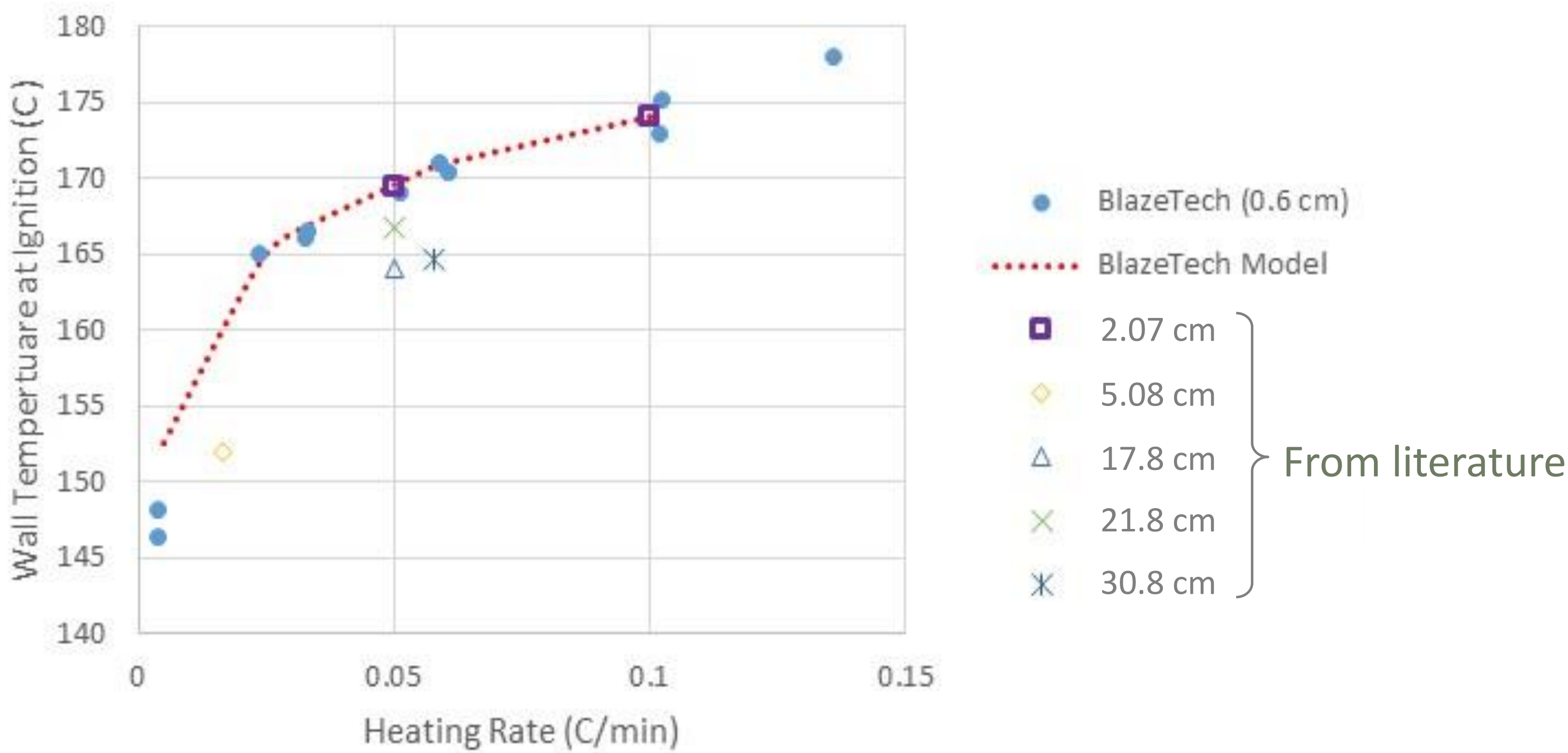
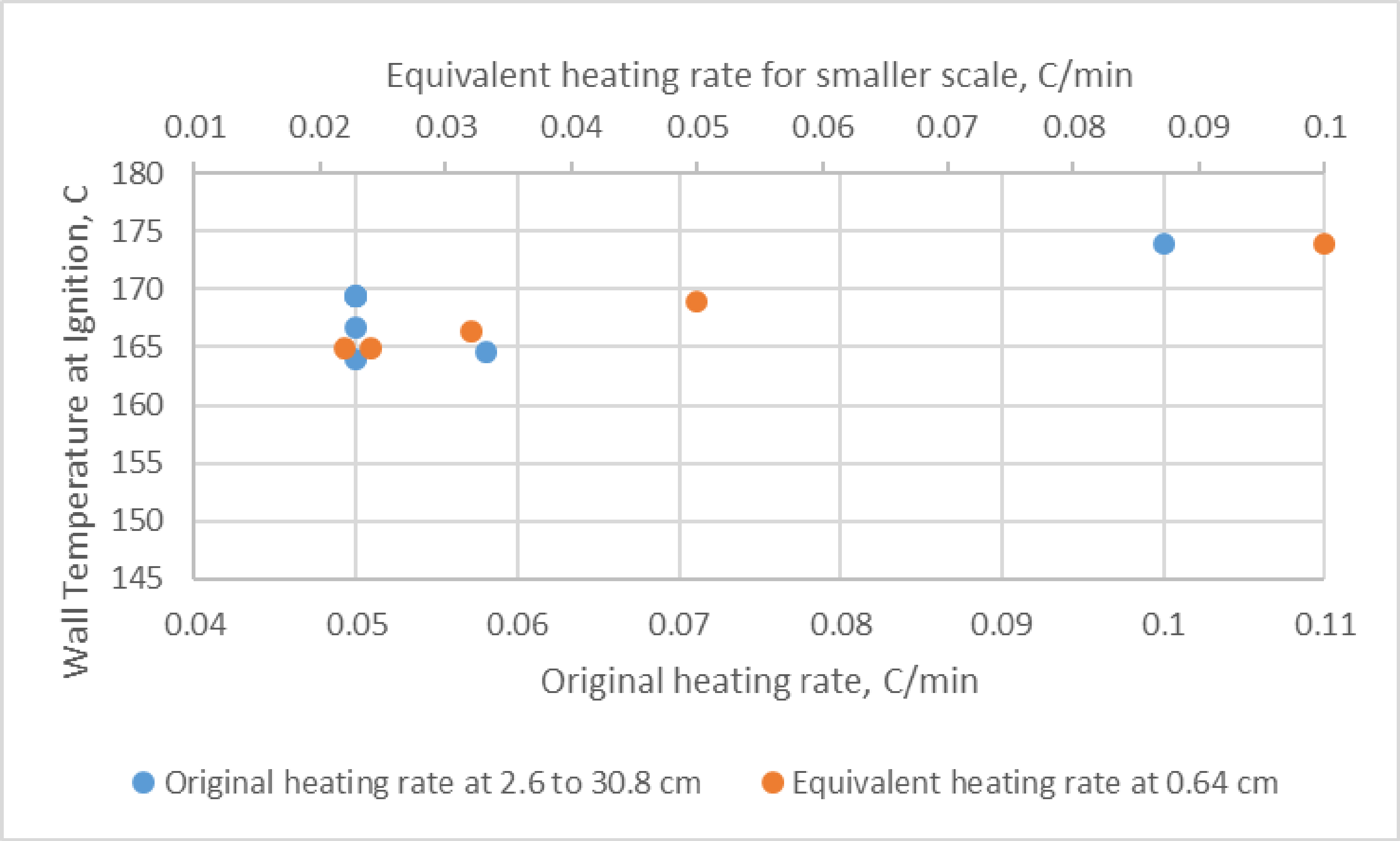
Our Measured and Predicted $T_{wall@ignition}$ (Plus literature data at various diameters)

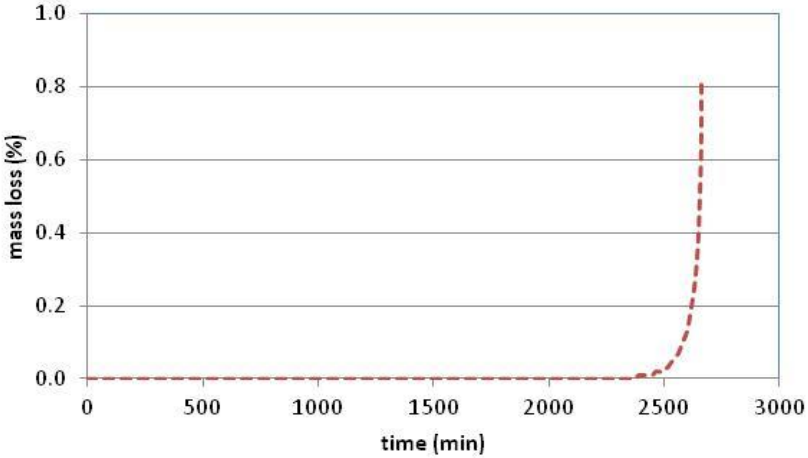


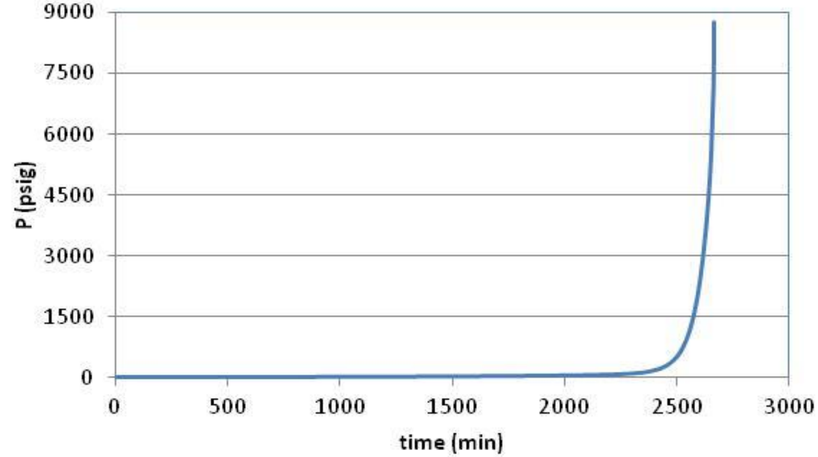
Model predictions shown only for BlazeTech tests

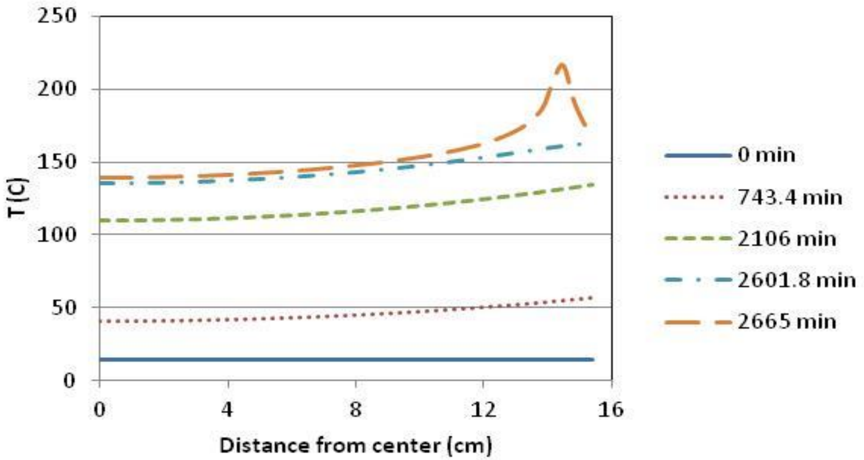
$T_{wall@ignition}$ from Various Sources vs. Original and "Equivalent" Heating Rates

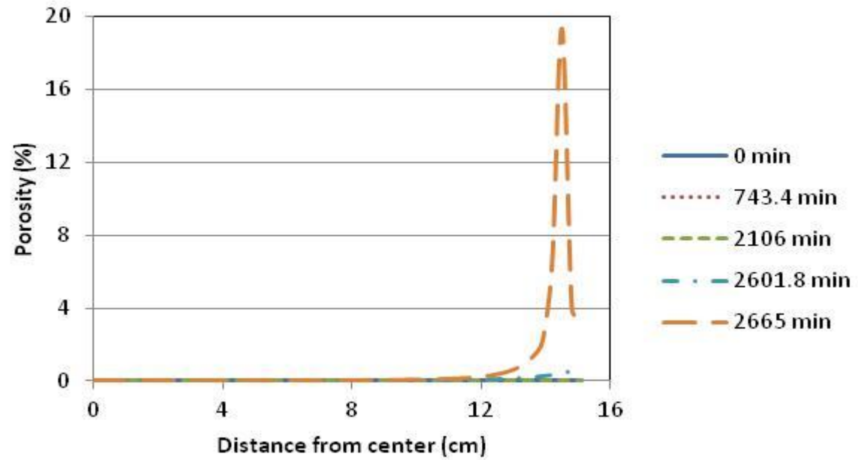


Other Model Predictions for a Sample Bomb









Summary

We have performed small scale tests on confined PBXN-109 and developed simple models for:

- The thermal degradation kinetics up to ignition
- The effect of thermal degradation on burn rate enhancement

We have developed a simple 1-D cylindrical model that incorporates heat transfer and the above models

Our predictions of $\mathbf{T}_{\mathbf{wall@ignition}}$ agree well with SCO data for various scales in literature

SCO and FCO can be handled by our model

Key Findings re Scaling SCO from our Tests and a Simple 1-D Model

1. At a given scale, $\mathbf{T_{wall@ignition}}$ increases with increasing heating rate
2. At a given heating rate, $\mathbf{T_{wall@ignition}}$ increases with decreasing scale
3. Choice of scale and heating rate are interrelated and can be given by our model in test design
4. Our work can be improved by performing similar tests at a larger scale

Relevance to Violence

We have developed data and a simple model that tracks:

- (1) Thermal degradation and (2) pressure prior to ignition and their effects on burn rate enhancement

Model can be extended to track violence in a simple way:

- To match violence between different scales, one needs to match (1) and (2)
- This matching can be obtained by adjusting the heating protocol and the test design
- Additional testing is needed

Our model can be used to evaluate methods to reduce violence.