Naval Surface Warfare Center Dahlgren Division

Analysis of the Ramifications of Increasing the Slow Cook-off Test Heating Rate

Presented by

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Overview

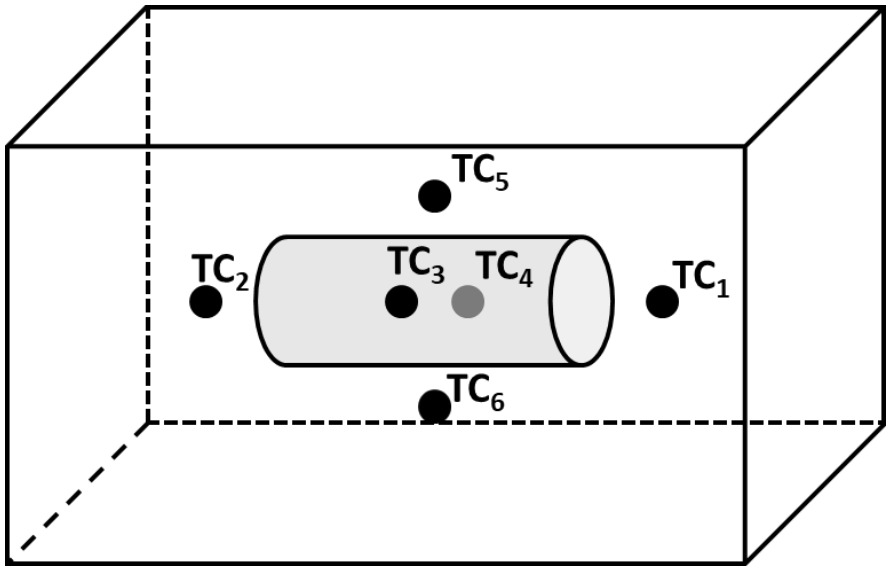
- The heating rate used for Slow Cook-off (SCO) testing is increasing from 3.3°C/hr to 15°C/hr
- Increasing the heating rate will effect other aspects of the test such as:
  - The temperature uniformity within the oven
  - The temperature profile within the munition
  - The maximum temperature during testing
- Testing resulted in:
  - Establishment of the new oven uniformity requirement
  - Measurement of reaction temperature increases
  - Demonstration of an oven design that meets the new standards

Part 1: Oven Uniformity

- The temperature uniformity of the air surrounding the test item must be controlled to ensure even heating is maintained
- Current test standard wording: “Some gradient in temperature between the input and exit air streams is to be expected, but this should not be greater than 5°C”
  - This wording is unclear, should instead focus on the air temperature around the test item
- Increasing the heating rate will increase the thermal gradients within the oven
- Testing was performed to:
  - Quantify historical temperature gradients
  - Determine how increasing the heating rate will affect these gradients

Oven Uniformity – Gradient

- The gradient (G) is the range (max – min) of the temperatures measured around the test item *at each time step*
- Historically 4 air temperature measurements were required but the new Allied Ordnance Publications (AOP) will increase to 6
  - 40-60mm off each surface

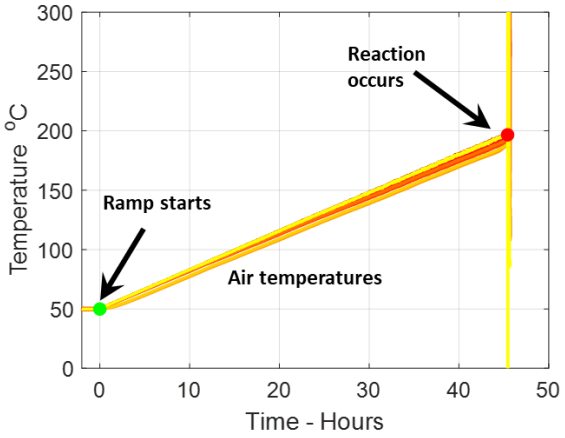


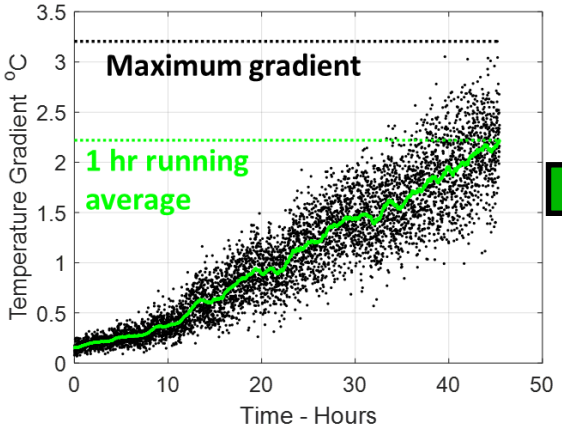
t_1	$T_{1,1}$	$T_{2,1}$	$T_{3,1}$	$T_{4,1}$	$T_{5,1}$	$T_{6,1}$	→	G_1
t_2	$T_{1,2}$	$T_{2,2}$	$T_{3,2}$	$T_{4,2}$	$T_{5,2}$	$T_{6,2}$	→	G_2
•••								
t_n	$T_{1,n}$	$T_{2,n}$	$T_{3,n}$	$T_{4,n}$	$T_{5,n}$	$T_{6,n}$	→	G_n

$$G_i = Max\left(T_{1\to6,i}\right) - Min\left(T_{1\to6,i}\right)$$

Gradient Statistics

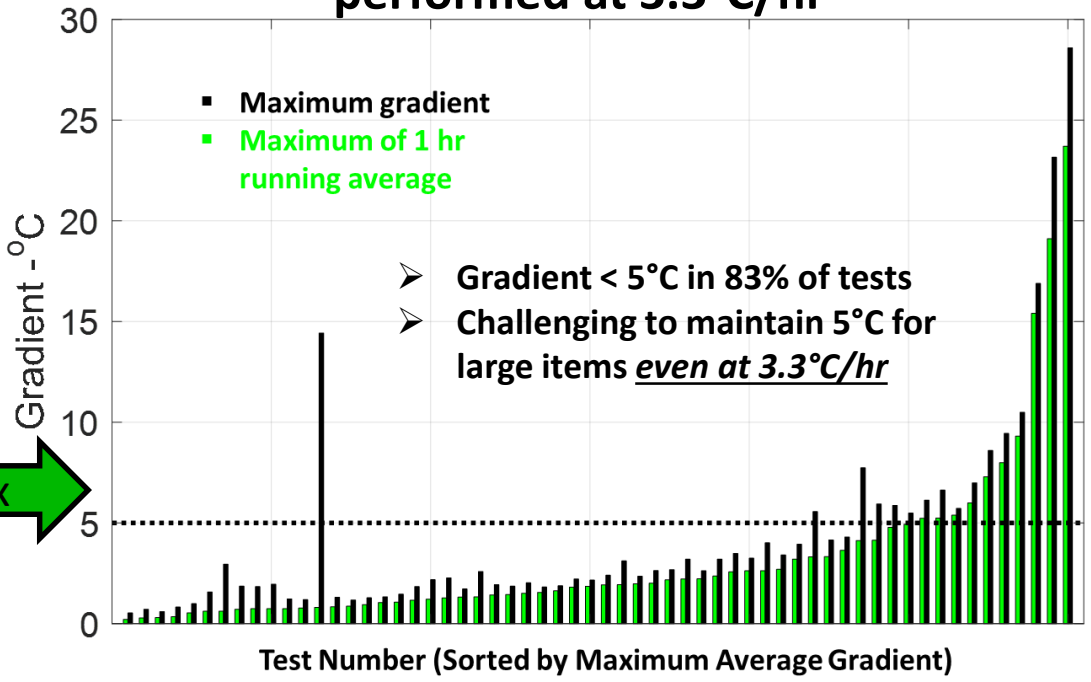
- Gradient is calculated throughout heating
- Gradients from 60 SCO tests performed at 3.3°C/hr were calculated
  - Gradient typically increases with temperature and item size





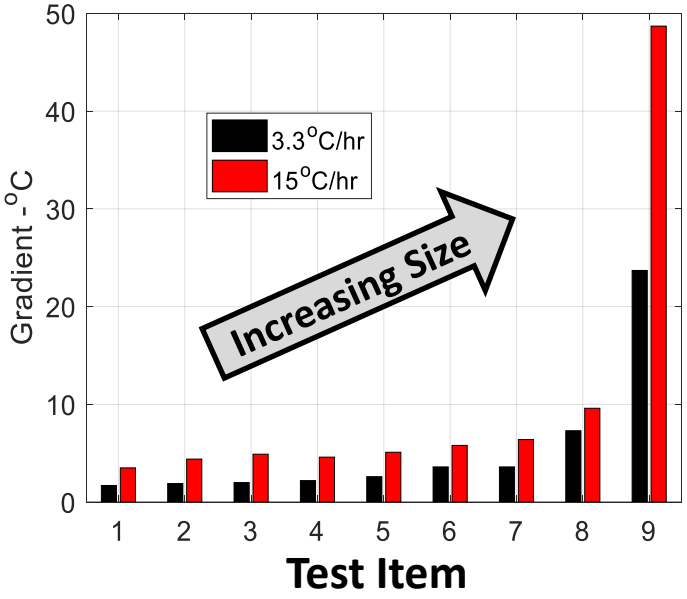
60x

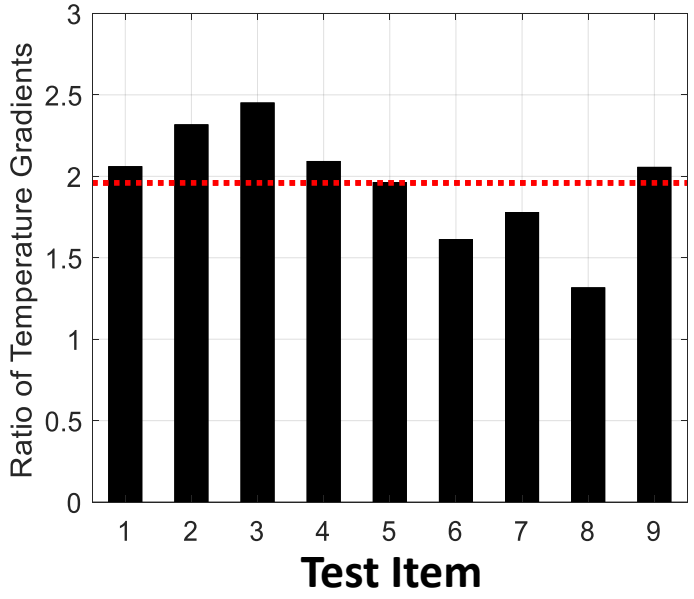
Gradient results from 60 SCO tests performed at 3.3°C/hr



Heating Rate Effect on Gradient

- Nine different items were tested at both 3.3°C/hr and 15°C/hr
  - On average, the gradient approximately doubled when the heating rate was increased
  - In all but the largest item tested the gradient was held below 10°C
- The new AOP now states that the gradient is based on the surrounding air temperatures and should not exceed 15°C



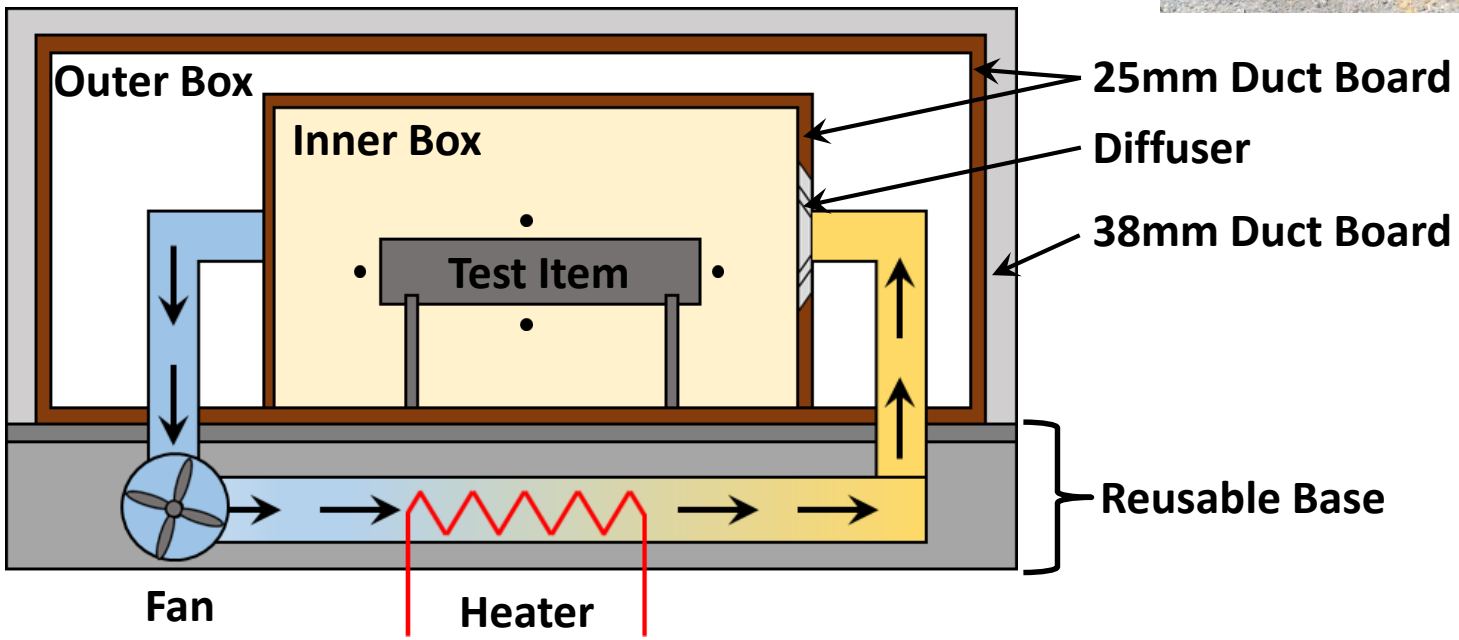


Part 2: Oven Capabilities

- It is known that the increased heating rate will result in higher cook-off temperatures
  - Increase is demonstrated in part 3 of this presentation
- There is concern that these temperatures could exceed the capabilities of the ovens currently being used
- A series of tests were performed to characterize NSWC Dahlgren Division's SCO oven at elevated temperature

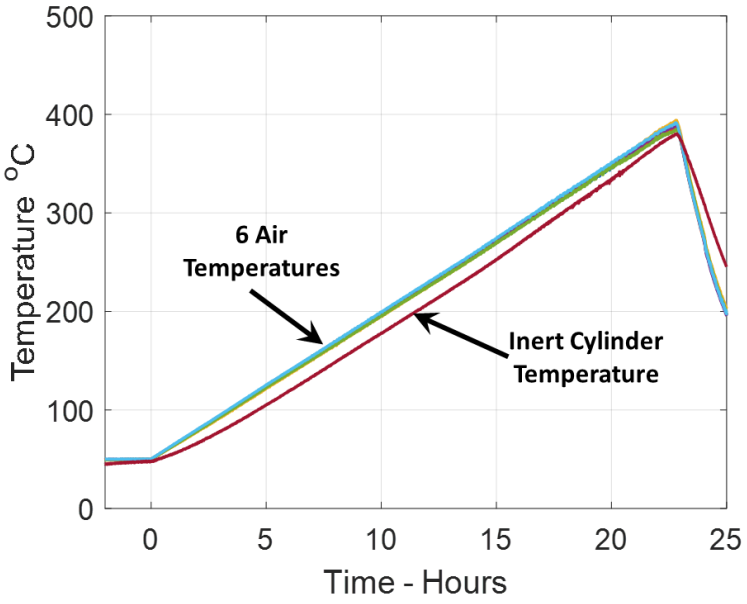
Oven Details

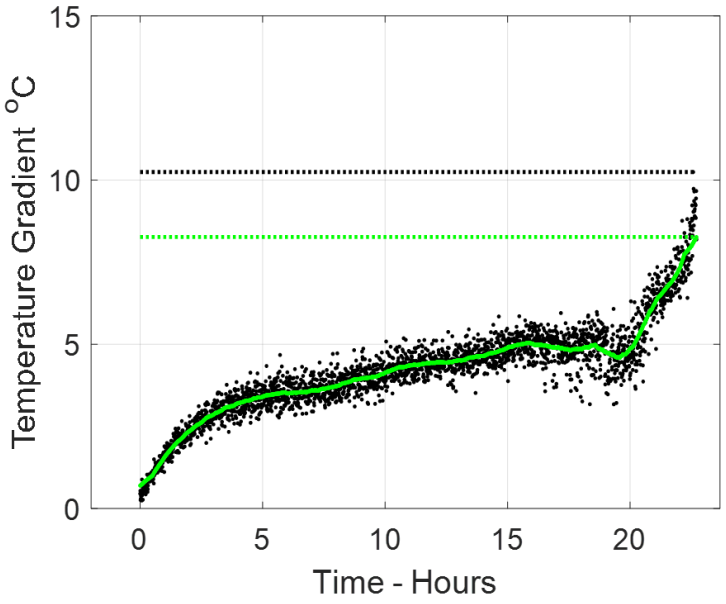
- Reusable, shielded base
  - Protects heater, fan, and ducting
- Double walled outer box
- Single walled inner box



Elevated Temperature Test

- Tests of inert cylinders to 375°C at 15°C/hr
  - 125°C higher than highest reaction temperature during energetic testing
- Oven maintained structural integrity
- Temperatures met AOP requirements
  - Maximum gradient well below 15°C limit





Part 3: Energetic Testing

- SCO tests of 5 different energetic items were performed at both 3.3°C/hr and 15°C/hr
  - Medium caliber vented High-Explosive (HE) projectile
  - Medium caliber gun ammunition, live propelling charge/inert (training practice) projectile
  - Medium caliber unvented HE projectile
  - Small vented rocket warhead
  - Mortar propelling charges in shipping container
- Each munition was inside its shipping container
- Temperature, blast pressure, and debris data were collected
- Each reaction was unofficially scored by a member of the Navy's Munition Reaction Evaluation Board (MREB)

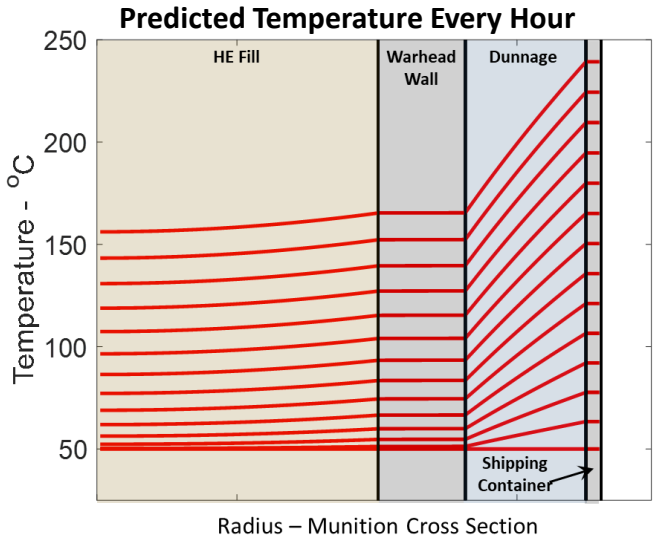
Energetic Testing Results Summary

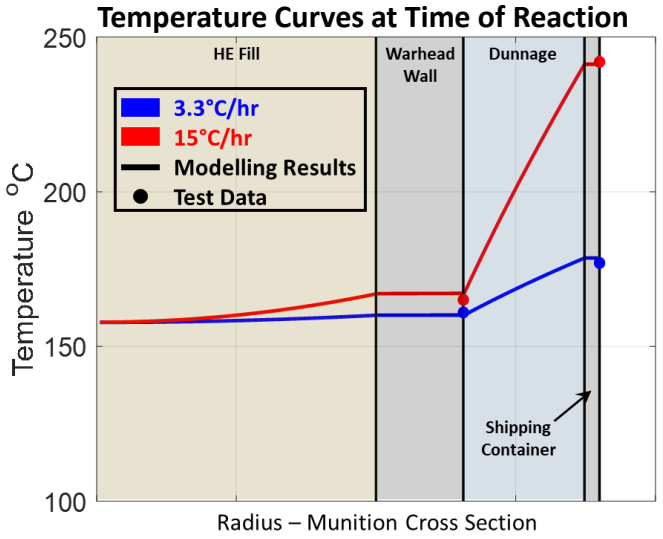
- For each of the five items tested, the heating rate did not affect the unofficial score
  - Minor differences in debris and blast pressure
- Increase in the oven air temperature when the reaction occurred
  - Increase ranged from 31°C to 67°C
  - Maximum reaction temperature: 247°C compared to 203°C

Test Item	Heating Rate (°C/hr)	Average Oven Temperature (°C)	Increase in Oven Temperature (°C)	Score
Medium caliber vented High-Explosive (HE) projectile, containerized	3.3	171	47	V
	15	218		V
Medium caliber gun ammunition, live propelling charge, inert projectile, containerized	3.3	142	53	IV
	15	194		IV
Medium caliber unvented HE projectile, containerized	3.3	180	67	I
	15	247		I
Small caliber vented rocket warhead, containerized	3.3	203	31	V
	15	234		V
Mortar propelling charges, containerized	3.3	131	35	IV
	15	166		IV

Munition Temperature Profile

- 1-D thermal code was used to analyze the temperature profile within munition
  - Example shown: unvented HE projectile
  - Air temperature increased linearly to simulate SCO test
  - Temperature slice shown at each hour
- Comparison of temperature profile at time of reaction
  - Good agreement between model results and measurements
  - Air temperature is 67°C higher but average energetic fill temperature is very similar
  - Temperature of energetic fill is less uniform at the faster heating rate





Summary

- Increasing the SCO heating rate from 3.3°C/hr to 15°C/hr presents new challenges to test centers
- The allowable temperature gradient within the oven has been increased from 5°C to 15°C
- Increasing the heating rate will increase the reaction temperature
  - Testing showed an average reaction temperature increase of 46.4°C for the five items tested
- The oven used by NSWCD Dahlgren Division has been shown to meet the new test requirements to a temperature of 375°C

Acknowledgements

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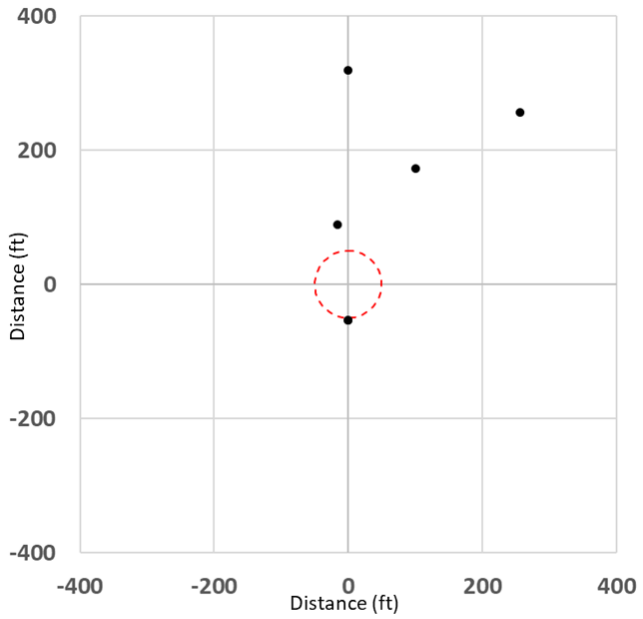
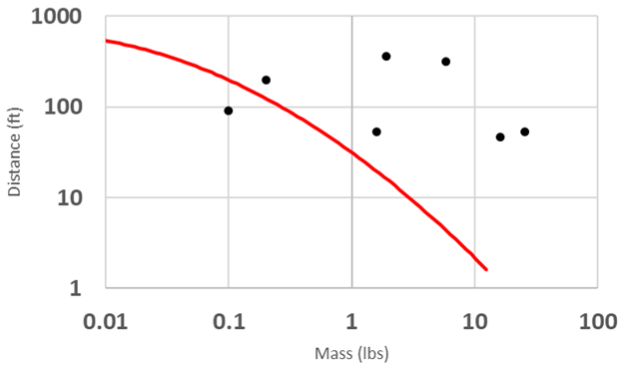
- BACK UP SLIDES

Example Debris and Energy Plots

- Medium caliber gun ammunition – live propelling charge, inert projectile

3.3°C/hr





15°C/hr