Fast Cook-Off Modeling and Simulation

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Modeling with experimental confirmation was the subject of our IMEMTS paper and poster presented in Nashville in 2016 [1]. We showed a very accurate time to reaction for a Navy rocket booster motor in a 25 x 25 inch square missile launcher canister made out of a carbon fiber composite material. A reaction time of 14 minutes was predicted before the test. The test showed the reaction to occur at 14 minutes. Since that time, the computer simulation was run for a 21-inch-diameter second stage rocket motor in an open fire. The prediction before the test was 244 seconds to reaction; the test showed 225 seconds to reaction. Calculations were then carried out for a very complicated third stage rocket motor with a composite case. The predicted time was 260 seconds; the experimental time was 240 seconds.

Finally, we had an opportunity to model the fast cook-off test of 110 rounds of 30-millimeter (mm) gun ammunition contained in an ammo can with a thermal protection system. We did not have accurate reaction rate chemistry data, so we used a generic values for an Arrhenius reaction rate for nitrocellulose/nitroglycerin propellant from a French paper, and computed a reaction time of 163 seconds, compared to 150 seconds from the experiment. We made no changes in the input or property data to converge the model on the experimental time.

In this problem, each cartridge case was modeled with its own propellant and primer. The thermal protection system consisted of fiberboard panels around the inner surface of the can. There also was a wide strip of canvas wound back and forth in the can separating the layers of cartridges. Having modeled the time to reaction, and realizing the model is likely to be predicting the evolution of decomposition products accurately, we are ready to start work on predicting the violence of the reactions. Results from the models will help our understanding of fast cook-off and lead to safer weapons.

This paper reviews the rocket motor calculations, then shows the work done on the ammunition can. A concept for how the method can be extended to the computation of reaction violence is shown.
Second Stage Rocket Motor

Predicted Reaction Time: 244 seconds, 20 seconds more than the test data time of 225 seconds.

Propellant Maximum Temperature

Heat Flux Reaching the Propellant
Predicted Reaction Time for TSRM: 260 seconds, 20 seconds more than the test data time of 240 seconds.
No one computer model is available to solve the problem of heat flow from the fire, through a container, into the rocket motor, and finally the response of the propellant. Our model consists of four sub models using the Sandia Fuego and Aria computer codes. Fuego is a reactive flow gas dynamics code that was used to model the fire with one application, and natural convection in the space between the container, or launcher canister, and the motor with a second application. These are both flows where the fluid motion is caused by buoyancy. The conduction of heat and pyrolysis of epoxy is converted to gaseous products and char. This process was modeled with Aria. The radiative heat input to the rocket motor was calculated using Aria inner-surface temperatures of the canister walls. Convective heating inside was computed using heat transfer coefficients determined from the second Fuego model. The heat flow through the chamber, insulation, and on into the propellant was computed with a second Aria model. The heat flow into the propellant causes self-heating of the propellant, which suddenly greatly exceeds the material’s ability to conduct heat to the outside, resulting in an explosion.
Pre-test model predictions and the test both showed cook-off at 15 minutes after ignition of the fire.
Second Stage Rocket Motor

Predicted Reaction Time: 244 seconds, 20 seconds more than the test data time of 225 seconds

COMPOSITE CASE TEMPERATURE (K) AT REACTION TIME

Propellant Maximum Temperature

Propellant Temperature (K) at Reaction Time

Heat Flux Reaching the Propellant
Third Stage Rocket Motor

Propellant Temperature

Gas Phase Concentration

Predicted Reaction Time for TSRM:
260 seconds, 20 seconds more than the test data time of 240 seconds
Fast Cook-Off of 110 30 mm Cartridges in an Ammo Can in a Propane Fire
Modeling Flow Chart for Ammunition Can

1) External average Temps for Radiation BC

2) Canister Internal Surface Temps for Calculation of Convection Heat Transfer Coefficient and Radiation

3) Internal convection Heat Transfer Coefficient

4) Solution:
   - Time To Reaction
   - Heat Fluxes
   - Temperatures
Steady state temperature field around ammo can at 75 seconds

After about 10 seconds steady state temperatures are attained
Geometry of Full Ammo Can and Temperature at the Time of Reaction

Metal, fiber board, and canvas

Fiberboard, canvas and packed rounds
Temperatures of Cartridge Cases Shortly After
the Reaction Began in the Lower Corners

Cartridge case temperatures during ramp
up to the reaction. The bottom corner
projectiles are starting to show more
heating.

Case head temperatures during the ramp up.
Temperatures are rising in the lower corner case
heads at a higher rate.
Cartridge Cases

Propellant inside of cartridge cases. The charge in the corner is evolving gaseous decomposition products (species B), 0.151 moles per liter.
Propellant Temperature in First Round to React

163 seconds, 423 K
Heat Fluxes Along Thermal Path to Propellant

Heat Flux (w/m²) vs. Time (Seconds)

- flux_3
- flux_10
- flux_40
Debris from Reaction

Exited Burner but <50 ft

Remained inside burner

Greater than 50 ft
Fast cook-off models have produced very good agreement with experiments for the time to reaction. The models also produce very useful data that could not be obtained otherwise, especially heat flux along the path from the fire to the reactive material. The models have been validated with data from three different rocket motors in conditions varying from a bare motor in the fire to a motor inside of missile launching canister made out of carbon fiber composite material. The models also predicted the explosion of an ammunition can full of live cartridges. The model showed the heating to be most severe in the lower corners of can. The model also included mitigation materials and could be used to further improve similar systems. The evolution of pyrolysis products was also calculated.

The next logical step in development of the technology is to augment the present models with another code we have experience with to calculate reaction violence.

The computer models could also be used to predict the reaction time for slow cook-off. The heating is mainly free and forced convection in ovens. Some of the fast cook-offs we have calculated for encanistered munitions start at the point of maximum natural convection. It would not be difficult to simulate all the heat flow paths in slow cook-off, including source and sink elements to simulate internal blowers.