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Effect of Pressure Vents on the Fast Cookoff of Energetic Materials

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Abstract

The effect of vents on the fast cookoff of energetic materials is studied through experimental modifications to the confinement vessel of the Radiant Heat Fast Cookoff Apparatus. Two venting schemes were investigated: 1) machined grooves at the EM-cover plate interface; 2) radial distribution of holes in PEEK confiner. EM materials of PBXN-109 and PBX 9502 were tested. Challenges with the experimental apparatus and EM materials were identified such that studying the effect of vents as an independent parameter was not realized. The experimental methods, data and post-test observations are presented and discussed.

CONTENTS

FIGURES

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1. INTRODUCTION

Thermal initiation (cookoff) of energetic material-laden devices (rocket motors and munitions) during accidental fires is an important safety concern. A munition within a pool fire is an example of a fast cookoff scenario that has significant potential for a catastrophic result. Beginning in 2007, a collaborative experimental and model development research program under the Joint Munitions Program (JMP) was initiated at SNL/NM to address energetic material response to fast cookoff. Prior efforts under this program have shown that chemical kinetics derived under subscale cookoff tests are suitable for the prediction of energetic material (EM) response under fast cookoff conditions [1-3]. This demonstration was achieved through the development of our Radiant Heat Fast Cookoff Experiment which is a benchtop experiment that confines an energetic material sample in a controlled and reproducible fashion and exposes it to constant incident heat fluxes common in fires. Temperatures within the sample near the heated surface are measured using thermocouples and the time-to-event is determined as a function of incident heat flux.

As follow on to this prior work, the effect of vents on the time to ignition and EM behavior was studied through modifications to the confinement vessel of the Radiant Heat Fast Cookoff Experiment. The goal was to establish a relationship between vent area, incident heat flux and EM response. This report provides a summary of the efforts and data collected to date related to venting during FCO. It will be shown that the experimental modifications were unable to establish the relationship between vent area and incident heat flux desired. Suggestions for improvement are provided.

2. ORIGINAL CONFINEMENT

The most recent design of the EM confinement vessel used in the Radiant Heat Cookoff Apparatus is one that ensures one-dimensional heating, no/minimal cover plate deformation, known boundary conditions, and a hermetic seal will be maintained on the EM sample until after ignition occurs [1]. This is accomplished by a two-part aluminum and PEEK (Quadrant EPP Ketron® PEEK 1000) surround that is sealed with a 6.35 mm thick, 7.62-cm-diameter aluminum cover plate painted with high emissivity Pyromark®. A ring-shaped knife edge is machined into the cover plate. As the bolts are tightened, the knife edge digs into the upper surface of the PEEK to provide a gas-tight seal on the upper face. Below the EM, an o-ring prevents gas leakage outside the support piston. A cutaway view of the confinement vessel appears in Figure 1.

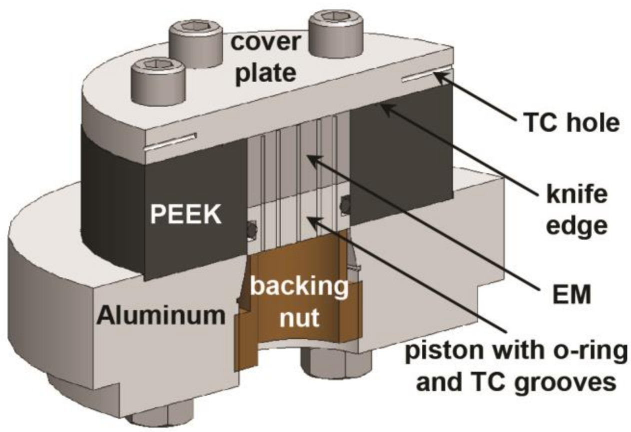


Figure 1. Cut-away illustration of the original EM confinement vessel of the Radiant Heat Fast Cookoff Experiment.

3. VENT SCHEME 1: MACHINED GROOVES IN COVER PLATE

To establish a constant vent area between the top surface of the PEEK and the bottom mating surface of the cover plate, the underside of the aluminum cover plate was machined with grooves between the bolt holes. The cover plate did not have a knife edge for sealing to the PEEK as in the original confinement design. Figure 2 provides a post-test photograph of the vent grooves between the bolt holes.

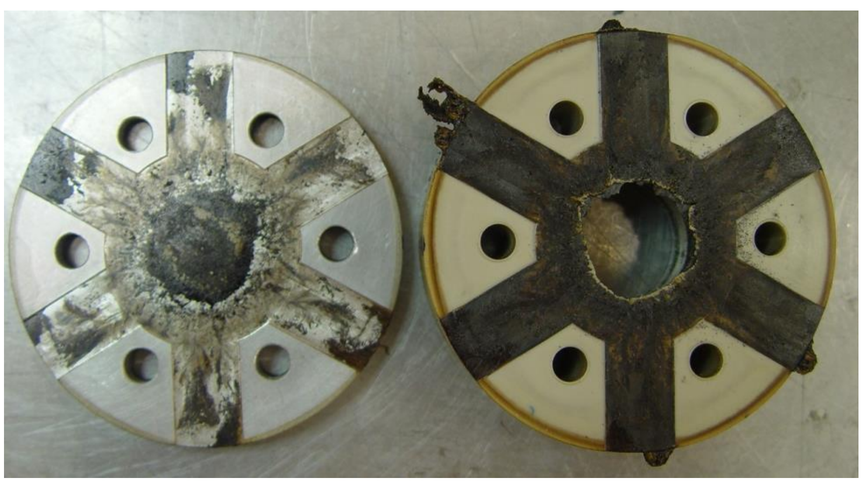


Figure 2. Post-test photographs of machined grooves on underside of the aluminum cover plate. The evidence of explosive residue is observed to have vented to the outer perimeter of the confinement through the machined grooves.

Table 1. Tests with PBNX-109 and Vent Scheme 1

	Heat Flux (kW/m^2)	Gap Height (mm)	Vent Area (mm^2)	Temp. (C)	Time (s)	Cover Plate Thickness (in)
FCO-70	79.8±2.1	0	0	144.4	177.3	0.251
FCO-71	80.6±2.2	0.1778	14	170.2	170.5	0.241
FCO-72	79.3±2.3	2.8448 (used steel washers on bolts)	227	162.2	162.2	0.2485

The data of Table 1 is plotted in the left plot of Figure 3 in terms of the time to ignition versus vent area. This plot shows an unexpected trend of decreasing ignition temperature with increasing vent area. For this configuration, it has been suggested that the cover plate is acting like a fin for collecting the incident radiant energy and transferring it directly into the EM. For the largest gap, the air space between the cover plate and PEEK at the outer perimeter is a better insulator than the heat transfer pathway into the EM. Thus, the larger gap results in a lower ignition time and a higher ignition temperature within the EM. For this configuration, the one-dimensional thermal profile carefully established in the original confinement vessel with tight contact between the entire surface of the cover plate and the PEEK or EM is not maintained in this vented configuration.

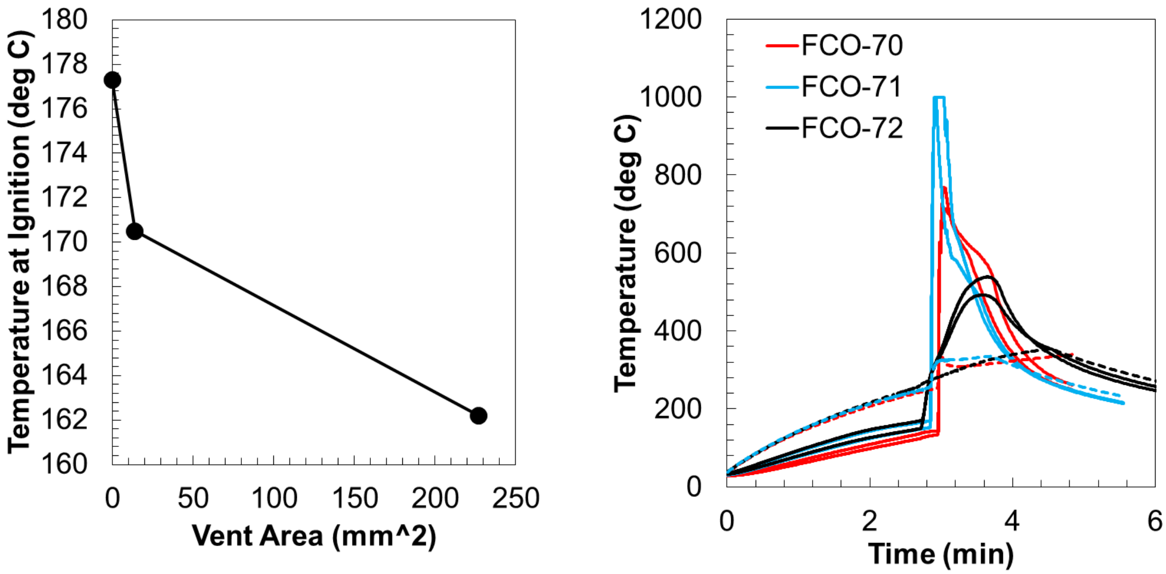
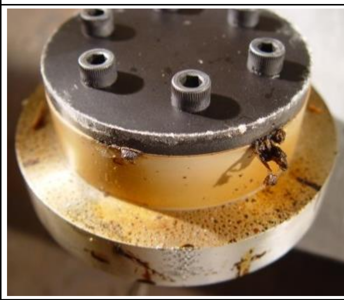


Figure 3. (Left) Plot of EM temperature at ignition versus vent area for the data of Table 1. (Right) Temperature histories for the tests of Table 1. The solid lines correspond to the temperatures measured at the center and outermost thermocouple (#1 and #9 in the TC array). The dashed lines correspond to the temperature history of the aluminum cover plate.

Table 2. Selected post-test images of the confinement vessel for the tests of Table 1.

FCO-70			
FCO-71			
FCO-72			

4. VENT SCHEME 2: RADIAL DISTRIBUTION OF VENT HOLES

The PEEK confiner has been modified to include an annular gap around the PBX 9502 (97%TMD) pellet. The PEEK confiner also may (or may not) contain vent holes with diameter equal to 0.036” (qty 5). The sixth space between assembly bolts is filled with a pressure transducer allowing for pressure to be collected in both vented and unvented tests. Figure 4 shows photographs of the PEEK confiner. The only thermocouples were installed in the cover plate.

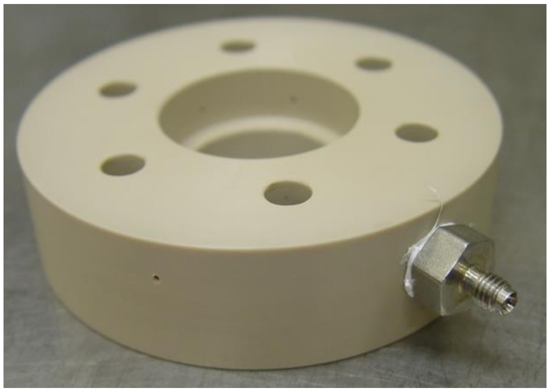
 

Figure 4. Photographs of machined annular gap and radial arrangement of vent holes in the PEEK confiner.

Table 3. Tests with PBX 9502 and Vent Scheme 2

	Heat Flux (kW/m^2)	Side Hole Size (mm)	Vent Area (mm^2)	Temp. (C)	Time (s)
FCO-73	293.0±4.4	0	0	412.4	75.8
FCO-74	290.2±6.2	0.9144	3.2835	537.0	113.4
FCO-75	101.6±5.2	0	0	386.2	327.3
FCO-76	52.6±2.1	0	0		

The data of Table 3 is plotted in Figure 5. The sealed PBX 9502 tests follow the typical relationship of time to event with incident heat flux. The single vented PBX 9502 test shows nearly an order of magnitude greater time to event with a small vent area.

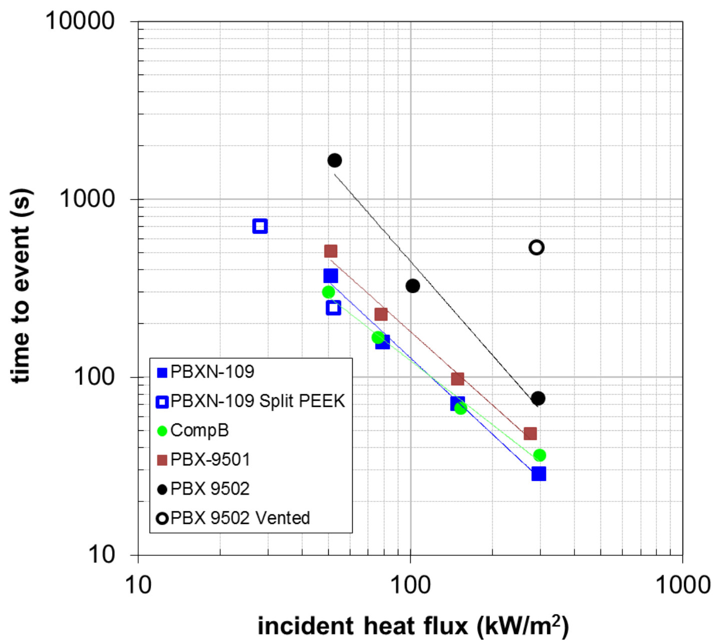


Figure 5. Plot of time to event with incident heat flux for the new PBX 9502 data of Table 3 and other previously tested EM [1].

In general, the pressure transducer showed several pressure excursions, only one of which seems correlated to the bulk ignition event that results in increasing the temperature of the cover plate. Similar “pops” and pressure excursions that are not the main ignition event have been observed in sub-scale slow cookoff testing (Ref. Figure 6.d of [4]).

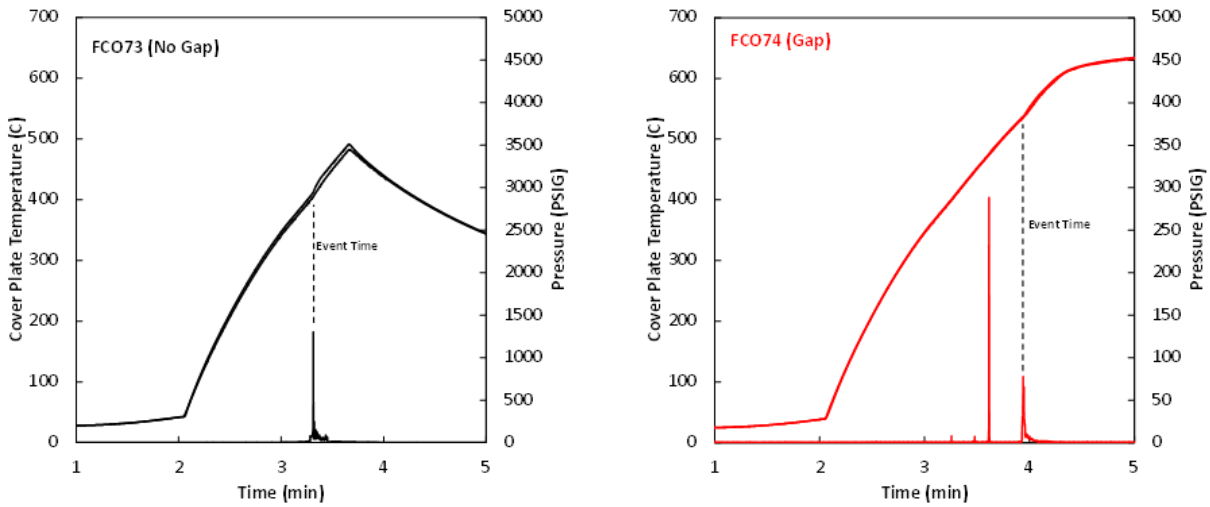


Figure 6. Plots of cover plate temperature and pressure histories for two tests with PBX 9502.

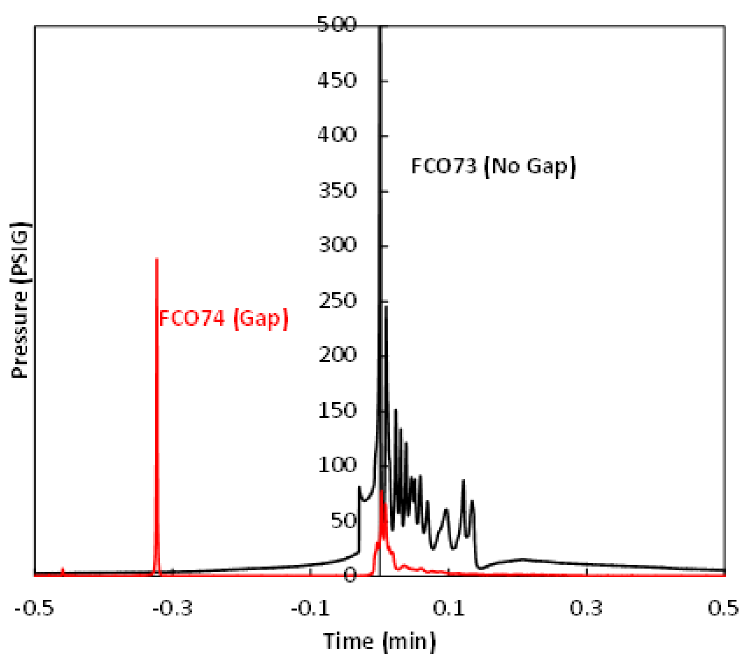
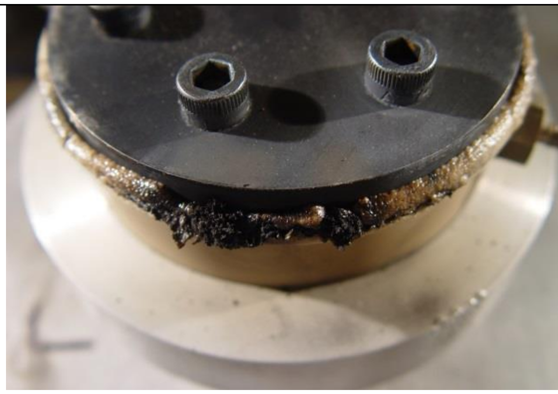
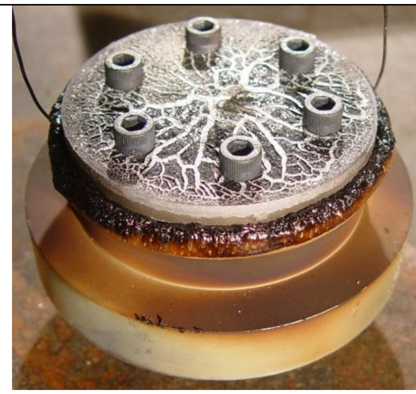
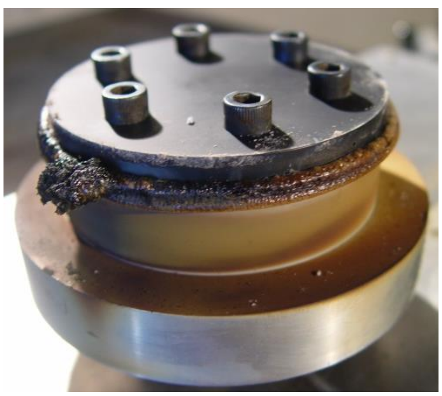
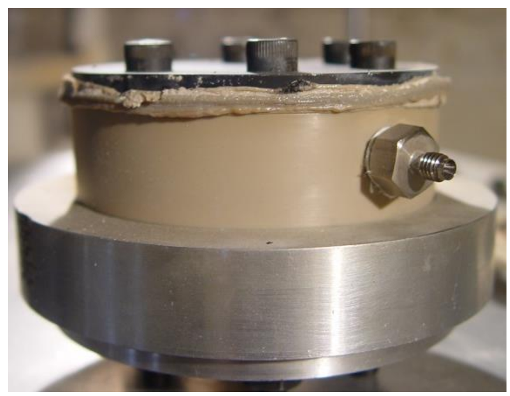


Figure 7. Comparison plot of pressure histories for the two PBX 9502 tests with and without vents.

While the vent scheme 2 seems to be affecting the EM response as expected (i.e., increasing time to event with increasing vent area), the PBX 9502 has a much higher ignition temperature such that significant dimensional changes occur in the PEEK at the cover plate-PEEK interface. This is shown in the photos of Table 4. It was determined that the high ignition temperature of PBX 9502 makes it not suitable for use with the PEEK material of the confinement vessel.

Table 4. Selected post-test images of the confinement vessel for the tests of Table 3.

 FCO-73	 FCO-74
 FCO-75	 FCO-76

5. CONCLUSION

Experiments studying the effect of venting under fast cookoff conditions is challenging due to the relatively fast time scales of heat transfer and the ignition location near the item's perimeter. The success of our original confinement vessel in the Radiant Heat Fast Cookoff experiment is entirely due to the care taken in the experimental design to establish a one-dimensional thermal profile within the EM [2]. The presence of large gaps that affect this one-dimensional thermal profile act to affect the ignition time and location such that a single dependent variable of incident heat flux is no longer present. It has been decided that a different experimental design is required to best elucidate the effect that vents may have on EM response under conditions of fast cookoff.

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