Effectiveness of Combustion of Shock-Dispersed Fuels in 6.6-l, 21-l & 40-l Calorimeters

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ABSTRACT

Investigated here is the combustion of a shock-dispersed-fuel charge consisting of 1-g flake Al in 6.6-l, 21.5-l and 40.5-l bomb calorimeters. Wall pressure histories were used to diagnose the effect of energy release due to turbulent mixing and combustion of the explosion cloud with air. These effects lead to a factor of 4.5 increase in the peak quasi-static pressure for the 6.6-l chamber. Pressure decay was observed at late times and was ascribed to energy losses to the walls due to radiation heat transfer.

EXPERIMENT

We consider the explosion-induced mixing and combustion of shock-dispersed-fuel (SDF) charges in cylindrical bomb calorimeters [1, 2]. A variety of fuels were tested; their heats of combustion are compared in Fig. 1. Flake Al SDF charges were found to be the most effective (i.e., create the largest pressure enhancement due combustion), and are reported here in detail.

The SDF charge (Fig. 2) consists of 0.5-g PETN spherical booster surrounded by a 1.0-g of flake Aluminum. The SEM photograph of the Al powder indicates a flake like structure of characteristic dimension 100 microns and a thickness of 1 micron.

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Figure 1. Comparison of the heats of combustion of various fuels.
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Figure 2. Construction of the SDF charge: (a) PETN booster; (b) SDF charge.

The SDF charge was placed at the center of the calorimeter, a right circular cylinder of L/D=1; calorimeter volumes of 6.6-l, 21.5-l and 40.5-l were used. Detonation of the SDF charge created an expanding cloud of explosion products gases and hot aluminum particles (fuel). When this fuel mixed with air, they formed a turbulent combustion cloud that consumed the aluminum, and liberated additional energy (31 kJ/g) over and above detonation of the booster that created the explosion. Explosions in a nitrogen atmosphere allow one to confirm the heat of detonation of the charge, while explosions in an air atmosphere allow one to study the dynamics of afterburning (combustion) in a confined explosion.

The main diagnostic consisted of 8 piezo-electric pressure gages (Kistler 603B) that were located at 5 and 7.5 cm radii on the lid of the vessel. To protect against heat transfer effects from the hot combustion products gases, the gauges were thermally insulated with a 0.1mm thick layer of silicon rubber. To check the influence of heating on the pressure, a pressure gage based on a different measurement principle (a piezo-resistive gage that is less sensitive to heat transfer effects) was employed. In addition, a photodiode was used to record the luminosity of the combustion cloud.

RESULTS

Pressure records for the explosion 1-g Al-SDF charge in the 6.6-liter calorimeter are presented in Fig. 3. Two cases are shown: (i) explosion in a nitrogen atmosphere (corresponding to the blast wave from the booster charge), and (ii) explosion in an air atmosphere. Their difference illustrates the dramatic effect that combustion of the Al has on the pressure waveform. Most of the combustion effects occur after the positive phase of the first blast wave; exothermic power is controlled by the turbulent mixing rate, which is fast compared to molecular diffusion processes, but slow compared to shock wave reverberations.
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The pressure records were filtered with a 0.5-kHz cutoff frequency to determine the mean pressure dynamics for the chamber. Results are presented in Fig. 4. It shows that the booster charge gives a late-time quasi-static pressure of 2 bars, while the explosion and combustion of Al-SDF charge creates about a peak quasi-static pressure of 9 bars. This requires about 3 ms, or 30 positive phase durations (~0.1 ms) of the blast wave to complete the combustion process.

Figure 3. Comparison of pressure records from the explosion of 1-g Al-SDF charges in air and nitrogen atmospheres in the 6.6-liter bomb calorimeter.

Figure 4. Comparison of filtered pressure records from the explosion of SDF charges in the 6.6-liter bomb calorimeter.
Experiments were also performed with a variety of fuels shown in Fig. 1 (sucrose powder, carbon powder, PE particles), and combinations of these fuels with aluminum. Peak quasi-static pressures measured for these SDF charges are presented in Fig. 5. The data exhibits an inverse dependence on fuel specific volume $v_F$:

$$\Delta p_{SDF} \text{ (bar)} = \frac{119}{v_F^{1.2}}$$

which represents an upper bound to the measured peak quasi-static pressures. This is to be contrasted with the measurements for TNT detonations in a nitrogen atmosphere (i.e. with no afterburning) which can be fit by:

$$\Delta p_{TNT} \text{ (bar)} = \frac{11.6}{v_F^{0.7}}$$

The effectiveness of the SDF combustion to enhance the late-time quasi-static pressure may be expressed by:

$$\varepsilon_{SDF} = \frac{10.3}{\sqrt{v_F}}$$

which represents the ratio of equations (1) and (2). At a fuel specific volume loading of 10 liters per gram, this gives a value of $\varepsilon_{SDF} = 3.3$; in other words, the combustion of the SDF charge will give a late-time chamber pressure that is 3.3 times larger than that found from the detonation of a TNT charge in the same volume ($v_F = 10 \text{ l/g}$).

**CONCLUSIONS**

Parametric experiments were performed with Aluminum SDF charges in a 6.6-liter bomb calorimeter. Pressure measurements were shown to be very reproducible and repeatable ($\text{rms}$ uncertainties of 0.05-0.10 bars). Comparing the peak quasi-static pressure measurements with constant volume explosion predictions based on the Cheetah code indicates that over 90% of the Aluminum was consumed during combustion with air. Experiments with other SDF fuels were performed in $V = 6.6, 20,$ and 40.5 liter chambers. These results confirm that one can combust a large portion of the fuel, thereby raising the mean chamber pressure by a factor of 3 or more. This enhancement factor, or *effectiveness of combustion*, depends on the fuel specific volume, and may be expressed as: $\varepsilon_{SDF} = \frac{10.3}{\sqrt{v_F}}$. We conclude that, in contrast to detonation, *combustion* is a more effective mechanism to increase the energy (pressure) content in sealed chambers.

**REFERENCES**


**ACKNOWLEDGEMENTS**

This work was performed under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48. It was sponsored by the Defense Threat Reduction Agency IACRO # 05-4071.
Figure 5. Maximum quasi-static overpressure measured in barometric calorimeters as a function of the fuel specific volume: $v_F$ for various aluminized SDF charges. These results are to be contrasted with data from TNT explosions in nitrogen (which contain about 1000 cal/g corresponding to the heat of detonation of TNT), which illustrate the dramatic increase in pressure caused by combustion for Al-SDF charges. The ratio of those two pressures, which we denote by combustion effectiveness, may be expressed by the power-law relation: $\mathcal{E}_{SDF} = 10.2 / v_F^{0.48}$. 