Shock-Dispersed-Fuel Charges – Combustion in Chambers and Tunnels

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Abstract

In previous studies we have investigated after-burning effects of a fuel-rich explosive (TNT). In that case the detonation only releases about 30 % of the available energy, but generates a hot cloud of fuel that can burn in the ambient air, thus evoking an additional energy release that is distributed in space and time. The current series of small-scale experiments can be looked upon as a natural generalization of this mechanism: a booster charge disperses a (non-explosive) fuel, provides mixing with air and, by means of the hot detonation products, the energy to ignite the fuel.

The current version of our miniature Shock-Dispersed-Fuel (SDF) charges consists of a spherical booster charge of 0.5 g PETN, embedded in a paper cylinder of approximately 2.2 cm^3, which is filled with powdered fuel compositions. The main compositions studied up to now contain aluminum flakes, hydrocarbon powders like polyethylene or hexosen (sucrose) and/or carbon particles. These charges were studied in four different chambers: two cylindrical vessels of 6.6-l and 40.5-l volume with a height-to-diameter ratio of approximately 1, a rectangular chamber of 4 l (10.5 x 10.5 x 38.6 cm^3) and a 299.6 cm long tunnel model with a cross section of 8 x 8 cm^2 (volume 19.2 l) closed at both ends.

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In the three smaller chambers the primary blast front arrives at **all** sidewalls within a short period (order of magnitude 100 µs) after the detonation and sets upon blast reverberations at correspondingly high frequencies. Depending on the volume, they thus limit the overall expansion (cooling) of the hot detonation products and the dispersed fuel cloud and provide an efficient stirring mechanism that mixes the fuel with ambient air. Fuel combustion manifests itself as a time-dependent increase of the quasi-static overpressure underlying the shock structure seen in recordings from wall pressure gages. For example, detonation of the bare booster of 0.5 g PETN creates a quasi-static overpressure of about 2.1 bar in the 6.6-l cylindrical bomb vessel, while an SDF-charge containing 1 g of aluminum flakes generates an overpressure of 9.2 bar. This level is obtained in less than 1.5 ms and indications of the additional energy release become noticeable as early as 200 µs after the detonation. The experimentally observed pressure level of 9.2 bar is close to a theoretical estimate of 9.7 bar. The estimate is based on a thermodynamic equilibrium calculation that yields the constant-volume explosion state of an adiabatic system containing the appropriate amounts of PETN, aluminum and air. This indicates fairly complete combustion of the aluminum in the 6.6-l vessel.

Other fuel compositions exhibit lower burning rates and less complete combustion. Also, going from the 6.6-l volume to the 40.5-l volume changes the dynamics: the increase of the quasi-static pressure is slower and the chances for incomplete combustion are larger. We assume this is due to the fact that the products cloud can expand further in the later vessel, thus cooling the products before the blast reflections and enhanced mixing set in. This would mean that the confinement (i.e., the fact that the charge is detonated in some sort of chamber along with its geometry) plays an important role in the performance of SDF-charges.

In the closed tunnel different dynamics of the blast wave propagation evolve. In the tests the charge was located near one end of the tunnel at $x = 1$ D. Reflections from the sidewalls, the floor and the roof are of importance only close to the charge location ($x < 7D$). By the time the waves reach $x \approx 7D$ they coalesce into a unique, quasi-one-dimensional front. Also, the tunnel walls constrain the mixing of the fuel with air to be quasi-one-dimensional (along the tunnel axis). Thus the mixing is less efficient in a tunnel, while at the same time the detonation products/fuel cloud cools down more rapidly (via heat losses to the walls).

Nevertheless, SDF-charges with aluminum flakes did generate additional energy release (in excess of the booster) in the tunnel. With the charge detonated close to one tunnel end, it takes the blast front about 4 ms to propagate to the other end of the current model. In this period combustion released energy initially generated additional pressure that filled in the decay of the blast wave and thus increased the positive overpressure impulse. Less than halfway down the tunnel the effects from the additional energy release even catch up to the front of the blast and cause an enhanced peak pressure versus range. At the end of the initial 4-ms period the SDF-charge with 1 g aluminum flakes appeared to be as efficient as a charge of about 1.4 g TNT in terms of the peak pressure and as efficient as a charge of 1.7 g TNT in terms of the positive overpressure impulse. This efficiency however, though proving at least partial combustion of the aluminum flakes, is below what one would expect from a comparison of the heat of combustion of the charges.

In summary, non-explosive fuel can be dispersed and ignited by a single booster charge. On the one hand the time-scale and the yield of the pressure effects depend on the fuel and its characteristics, like composition and particle size and geometry. On the other hand a confinement seems necessary to take advantage of the combustion energy; time-scale and yield thus also depend on the flow dynamics in the chamber and in consequence on the chamber geometry and volume. For optimum performance the cooling rate of the detonation products / fuel cloud and the mixing with ambient air have to be well balanced.

Figures

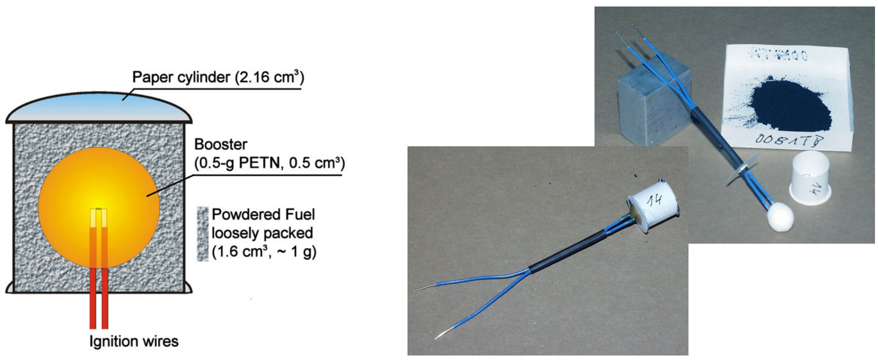

Figure 1 *Schematic sketch of the SDF charge design (left) and photographs of a charge and its components (right).*

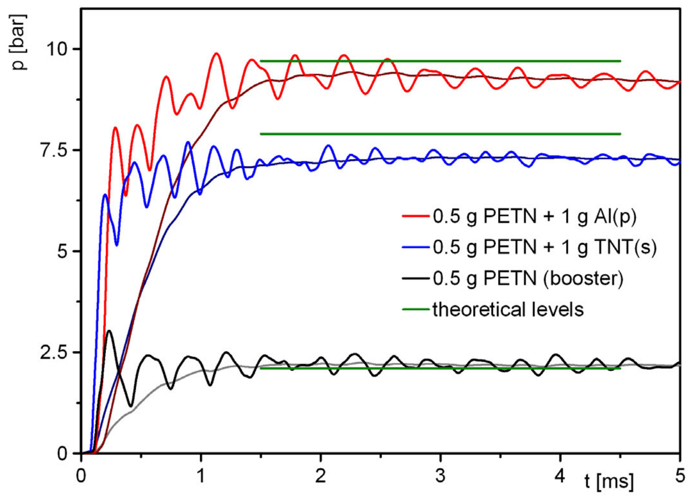

Figure 2 *Overpressure vs. time in the cylindrical 6.6-l vessel for three charges: the bare booster (0.5 g PETN), a composite charge (a core of 0.5 g PETN, a solid outer shell of 1 g TNT) and the SDF charge containing 1 g Al-flakes. The records are low-pass filtered for readability. At a cut-off frequency of 2 kHz remainders of the shock reverberation structure are still visible, a cut-off of 0.5 kHz smoothes these oscillations, but falsifies the initial pressure rise rate. Included in this figure are theoretical pressures levels based on a thermodynamic equilibrium calculation of the constant-volume explosion state (green lines).*

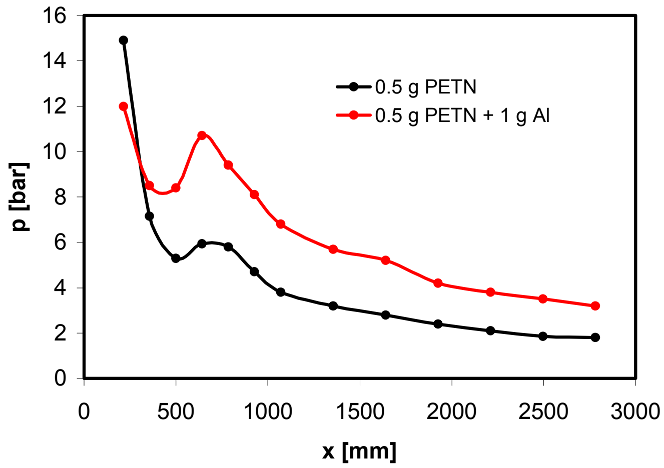

Figure 3 *Peak pressure vs. range in the 3-m long tunnel model for the booster and the SDF charge containing Al-flakes.*