Investigation of initiating strength of detonators containing TXX 50, MAD-X1, PETN, RDX, HMX, or PETN as a base charge

Thomas M. Klapötke(1), Tomasz G. Wiltkowski(2), Zenon Wilk(1), Justyna Hadzik(1)

(1) Institute of Inorganic Chemistry, University of Münster, MIU, 48149 Münster, Germany
(2) Department of Chemical Engineering, University of Gdansk, 80-952 Gdansk, Poland

Abstract

An experimental investigation of the initiating capability of detonators containing as a base charge the following explosives: dicyanamid (4,4’-azoxyxyl) – TXX 50, dicyanamid (4,4’-azoxyxyl) – MAD-X1, PETN and RDX in comparison with HMX and PETN was undertaken. In order to estimate the initiating capability of detonators, the underwater explosion test was applied. The total energy as a sum of the primary shock wave and the bubble gas energies was determined by measuring the overpressures of the shock waves generated underwater. The explosion gas release determined by a new method of the gas release velocity was used to calculate $\Delta h_{\text{g}}$. The performance parameters (such as detonation energy, detonation pressure, detonation velocity) based on calculated $\Delta h_{\text{g}}$ values were computed using the CHEMTIA 2.0 software. For the calculations the theoretical maximum densities and densities obtained during the experiments presented in this work were used.

Introduction

Recently, many new types of detonators have been developed and implemented for production. The continuous research for new types of detonators is driven by increasingly strict safety requirements and environmental concerns, protection against unauthorized use, as well as specific requirements set by users. In order to fulfill these requirements, novel explosives with tailored properties which have been recently synthesized, could be used as the base charge in detonators [1-4]. Nevertheless, the shock wave generated during the detonation of the base charge is generated at a higher than the initiation pressure of the acceptor explosive charge. If the generated shock wave is not sufficient to initiate the detonation of the explosive, it can result in low-order detonation or misfire [5]. Therefore, the energy output of detonators containing new explosives as a base charge has to be determined and compared with currently used ones.

Materials and Methods

Among the recently developed explosives, the most promising candidates for application based on their performance as well as convenient synthetic method are TXX 50, MAD-X1, PETN and DAA (Figure 1).

The explosives (shown in Figure 1) have high decomposition temperatures (at 298 °C) and the theoretical maximum densities are 1.76 and 1.90 g/cm³. TXX 50, MAD-X1 and DAA are endothermic compounds, while PETN (similar to its analog PETG) is an exothermic compound, which contains four explosive nitro functionalities. Theoretically computed Chapman-Jouguet (CJ) characteristics of these explosives (detonation pressure, 23.47 – 23.49 GPa, detonation velocities, 7153 – 7159 m/s), as well as their sensitivity to external stimuli (FS ≥ 120 N, $\phi$ ≥ 2.7), also make these species interesting for possible application.

In order to estimate the initiation power of the detonators, the underwater initiating capability test was applied. The primary shock wave energies and the bubble gas energies were determined by measuring the overpressures of the shock waves generated underwater. Measurement of the shock wave and the time between the primary shock wave and initial pulsation of the gas bubble, allows the energies of the shock wave and gas bubble to be determined. The parameters allow a comparison to be made between the investigated explosives with currently used explosives (RDX, HMX, PETN) [6-9].

Underwater explosion

The initiating capability of detonators containing TXX 50, MAD-X1, PETN and DAA as a base charge was measured in underwater explosion test according to the methodology described in European Standard (EN 13763-15). Determination of equivalent initiating capability [8]. Additionally, commercial available explosives (RDX, HMX, PETN) were used as reference materials. In order to perform the underwater explosion tests, a water tank made from non-reflecting and energy-absorbing material with a positioning system for the sensor and detonator was used (Figure 2).

The detonators being tested were placed in the positioning system. Detonation of the explosives generates overpressures in water which were recorded by a piezoelectric transducer. The collected data are presented in two time scales. First one takes into account the presentation of the primary shock wave generated in water (t < 50 μs) which is used to determine maximum of overpressure ($P_{\text{max}}$) and time at which the sensor output has decreased to $P_{\text{max}} - P_{\text{EPAV}}$ (9,5), and calculation of $E_{\text{SPP}}$ and $E_{\text{SS}}$ (Figure 3a). The second time frame (t > 50 μs) is used to determine the time interval between the shock-wave pressure peak and the first collapse of the gas bubble ($t_0$, which is used to calculate $E_{\text{SBPP}}$ and $E_{\text{SB}}$ (Figure 3b).

The following oscillograms present the primary shock wave for reference explosives (RDX, HMX, PETN) and novel ones (TXX 50, MAD-X1, PETN, DAA) (base charges: 0.2 g, 0.55 g, 0.7 g respectively) (Figure 4).

![Figure 4](https://via.placeholder.com/150)

The following oscillograms present the first bubble pulsation for reference explosives (RDX, HMX, PETN) (base charges: 0.2 g, 0.55 g, 0.7 g) and novel ones (TXX 50, MAD-X1, PETN, DAA) (base charges: 0.2 g, 0.55 g, 0.7 g) (Figure 5).

Conclusions

The initiating capability of detonators containing as base charge TXX 50, MAD-X1, PETN and DAA in comparison to RDX, HMX or PETN under an underwater explosion test was determined. Determined values obtained for base charge are lower than 1.0. The lowest values of densities in comparison to TMD are obtained for TXX 50, MAD-X1, PETN and DAA (86.29, 84.56, 83.00 % TMD, respectively). The differences in the densities obtained are due to the methodology used, i.e. the same pressure (4.40 MPa) for all investigated explosives. That has direct impact on the primary shock wave generated in water, maximum of overpressure, the time interval between the shock-wave peak and the first collapse of the gas bubble as well as calculated on those data values i.e. the shock wave and bubble energies generated in water. Nevertheless a constant value of pressing pressure was used for comparative reasons. Therefore additionally, underwater test results are supported by calculated detonation parameters at obtained densities.

Reference explosives (RDX, HMX and PETN) possess the highest values of the peak overpressure. Nevertheless, novel explosives are characterized by slightly lower values of the recorded maximum overpressure (DAA = 58.69, MAD-X1 = 99.35, TXX 50 = 86.97, PETN = 81.81 % of RDX). Similar tendency appears for the time of increasing of the overpressure to $P_{\text{max}}$. Those factors show that primary shock waves generated by investigated explosives possess similar nature.

The highest values of time of the first bubble collapse are also obtained for reference explosives; however, new explosives differ from RDX not more than 7% of MAD-X1 = 98.31, DAA = 97.47, TXX 50 = 95.04 % PETN = 97.02. Of RDX indicates also significant action of detonation waves at longer distance from the point of initiation. The total energies as sum of primary shock wave energies and the bubble gas energies were determined. The highest value of the total energy acquired for 0.7 g base charge mass was for PETN (104.32 RDX), the lowest for DAA (78.29 RDX), MAD-X1, DAA and PETN possess also high values of the total energy (93.04%, 91.19%, 84.97% of RDX, respectively). The primary shock wave energy (which corresponds to blushiness of explosive) for investigated explosives is between 28.18% (PETN, 0.2 g of base charge) and 30.97% (HMX, PETN 0.7 g of base charge) of the total energy. Endothermal explosives show following contribution of shock wave energy to the total energy: DAA = 29.03%, TXX 50 = 28.05%, MAD-X1 = 28.98%. The second part of the total energy namely bubble energy, which correlates with heating power of explosive, is for investigated species higher than 60.01% of the total wave.

Moreover, presented technique can be also used as a comparative method; therefore the shock wave and bubble energies equivalents are also given. Thus the small scale underwater test can be useful tool for determining and recommending blast parameters (blushiness, burning power) of different explosives. It is characterized by small amount of tested species, and a great amount of information which can be obtained from the tests.

Therefore we can conclude that the obtained data are consistent and show that the explosives presented can be used as based charges in detonators. In their requirements which are demanded from energetic materials intended for use in detonators. In order to maximize performance parameters pressing pressure should be optimized for every explosive separately.

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