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BLAST PERFORMANCE OF ISOPROPYL NITRATE - BASED THERMOBARIC EXPLOSIVES VS. CAST-CURED PBX

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Abstract: *Thermobaric explosives are currently among most studied energetic formulations, due to their extraordinary combination of blast and thermal effects. They may be in the form if liqud explosive mixtures, often denoted as fuel-air explosives (FAE) or solid explosive charges, as solid fuel-air explosives (SFAE) or thermobaric explosives (TBE, TBX). This study compares the blast effect of selected formulations of the two types of thermobarics in field test. As FAE, compositions were prepared based on gelled isopropyl nitrate with metal particles as fuel component, and as TBE a multi-component polymer bonded explosive (PBX) was prepared, based on octogene, aluminium powder, ammonium perchlorate and a polymer binder. The selected explosive formulations were prepared as cylindrical charges of 5 kg and activated with electric detonator at 2 m height in open field test. The characteristics of the blast wave in air (maximum overpressure, duration of the positive phase of the pressure and impulse) were measured at different distances from the activation spot, using piezoelectric gauges. Also, the thermal effect of the explosions was observed with infra red imaging technique.*

Keywords: *thermobaric explosives, isopropyl nitrate, cast-cured PBX, blast performance, explosion.*

1. INTRODUCTION

Thermobaric explosives represent a class of energetic materials highly regarded for their unique ability to produce devastating blast and thermal effects. They are distinguished by their formulation, which can either be in liquid form, such as fuel-air explosives (FAE), or in solid form, known as solid fuel-air explosives (SFAE) or simply as thermobaric explosives (TBE or TBX) [1-6]. These explosives harness a combination of fuel and oxidizer components that, when detonated, undergo rapid combustion in the surrounding atmosphere.

In the context of this study, researchers focused on comparing the blast effects of two specific types of thermobaric explosives through field tests. For the FAE type, the compositions were developed using gelled isopropyl nitrate with added metal particles as the fuel component. On the other hand, the TBE variant consisted of a complex multi-component polymer bonded explosive (PBX) comprising octogene (HMX), aluminum powder, ammonium perchlorate, and a polymer binder [5, 7-10].

Isopropyl Nitrate (IPN) is a liquid fuel component commonly used in fuel-air explosive (FAE) formulations. FAEs are known for their ability to disperse a cloud of fuel in the air, which upon detonation creates a highly energetic blast and thermal effect. The basic principle involves the rapid vaporization and subsequent combustion of the dispersed fuel in the presence of atmospheric oxygen. IPN is a volatile liquid with a relatively low boiling point, which facilitates its rapid vaporization upon detonation. FAE formulations typically include additives such as metal particles or fine aluminum

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or magnesium powder to enhance the combustion efficiency and increase the blast yield [8, 11]. Initiation is usually achieved via an electric detonator, triggering a rapid combustion process that propagates through the dispersed cloud of fuel. IPN-based FAEs are known for generating high-intensity blast waves characterized by significant overpressure and impulse. The blast wave's duration and spatial distribution of pressure are critical parameters measured to assess its effectiveness. In addition to the blast, IPN-based explosives produce intense thermal radiation due to the combustion of the fuel-air mixture, which can cause secondary damage and fires in surrounding structures.

Cast-Cured thermobaric PBX are often made of central core of high brisance and surrounding thermobaric charge of annular shape, or they can be monolithic charges. Explosive core typically includes high-energy materials like octogene (HMX) or other energetic compounds, often blended with aluminum powder for enhanced energy release. Polymer binder serves to bind the explosive particles together, providing structural integrity and allowing for casting into various shapes. The PBX mixture undergoes a curing process where the polymer binder solidifies around the explosive particles, forming a homogeneous composite. Cast-cured PBX explosives are designed to produce controlled and predictable blast effects, characterized by a well-defined shock front and relatively stable pressure profile. The energy release is efficient and tailored to specific applications. The polymer matrix enhances the mechanical properties of the explosive, making it suitable for shaped charges and other specialized configurations. PBX explosives are favored for their ability to be shaped and molded into various forms, allowing customization based on operational requirements [5].

IPN-based FAEs tend to have higher energy yields per unit mass due to the rapid vaporization and combustion of the liquid fuel, leading to more extensive blast effects over a larger area. Cast-cured PBX explosives offer greater precision and control over the blast wave characteristics, making them suitable for applications where a specific blast profile or shaped charge effect is required. The choice between IPN-based FAEs and cast-cured PBX depends on factors such as operational environment, target specificity, and desired blast effects (e.g., shockwave intensity, thermal impact). While IPN-based FAEs excel in generating widespread and intense blast effects through rapid fuel combustion, cast-cured PBX explosives offer enhanced precision and tailored blast profiles suitable for specialized applications. Understanding these differences allows for informed decision-making in selecting the appropriate explosive type based on operational requirements and tactical objectives.

2. EXPERMIENTAL PART – MATERIALS AND METHODS

2.1. Experimental charges preparation

The experimental setup involved preparing cylindrical explosive charges weighing 5 kg each, in thin plastic casings 150 mm in diameter. IPN-based charges were prepared by adding metal powder while intense steering using a propeller mixer. Gelation agent, fumed silica, was added to obtain the consistency of gel. Aluminium and Magnesium powders were used, with spherical particles. These experimental charges had a cylindrical central explosive core made of pressed explosive FH-5 (RDX/montan wax=95/5, ∅25 mm, 62.5 g in total). Regarding the TBE PBX, it was a solid charge of a multi-component composition HMX/AP/Al/HTPB, produced by casting technology, without central explosive core [5, 10].

2.2. Blast performance testing

The prepared experimental charges were detonated at a height of 2 meters in an open field environment. The detonation was initiated using an electric detonator. To assess the blast wave characteristics, air shock-wave parameters were measured at different distances from the detonation point using piezoelectric gauges – pencil probes PCB, including the maximum overpressure generated by the blast wave, the duration of the positive phase of the pressure wave, and the impulse generated by the explosion. In addition to blast effects, the study also investigated the thermal impact of the explosions using infrared imaging technique: IR camera FLIR SC7200 was applied in measuring range 1500-2500 °C, with 50 mm objective, emissivity 0.95 and recording frequency 1466 Hz. This aspect of the research aimed to capture and analyze the thermal signature produced by each detonation, and to compare the heat released depending on thermobaric composition. IR camera was placed at a safe distance of 50 m from the sample.High speed camera Phantom V2112 was used to observe the appearance of the thermobaric fireballs after the activation of the charges.

3. RESULTS AND DISCUSSION

3.1. Parameters of the shock wave in air

Blast parameters at different distances from the activation spot of the examined thermobaric charges, read from the registered pressure-time dependence diagrams, $\Delta p = f(t)$, are given in Tables 1-3.

Table 1. Maximuim overpressure P_{max}

Composition	P_{max} [bar] at distance from explosive charge [m]				
	3 m	4 m	5 m	7 m	9 m
IPN	1.206	0.624	0.389	0.211	0.138
IPN/Al	3.520	1.697	1.104	0.516	0.438
IPN/Mg	3.064	1.718	1.134	0.571	0.461
TBE PBX	3.011	1.841	2.005	0.659	0.383

Table 2. Pressure impulse $I_p \times 10^{-4}$, [mbar·s]

Composition	Pressure impulse $I_p \times 10^{-4}$, [mbar·s] at distance [m]				
	3 m	4 m	5 m	7 m	9 m
IPN	9.761	7.394	6.884	4.076	3.858
IPN/Al	19.148	16.173	19.468	13.433	12.949
IPN/Mg	19.670	16.875	20.453	14.229	13.841
TBE PBX	21.550	19.356	22.079	13.818	13.66

Table 3. Duration of the overpressure positive phase, t

Composition	Positive phase duration, t [ms] at distance [m]				
	3 m	4 m	5 m	7 m	9 m
IPN	1.725	2.155	2.585	5.195	4.965
IPN/Al	1.670	2.230	5.915	5.700	6.125
IPN/Mg	2.235	2.175	3.205	5.865	6.590
TBE PBX	1.915	2.715	6.405	7.40	8.770

The diagrams Δp = f (t) that were registered are similar − after a sharp peak at the beginning, the maximum overpressure decreases and then suddenly sharply rises due to the appearance of the reflected shock wave. As illustrative example, Δp = f (t) diagrams for the samples IPN/Al, IPN/Mg and TBE PBX are shown in Figure 1. Reflected shock waves for the sample of TBE PBX were registered somewhat later compared to IPN based charges. Thermobaric charge TBE PBX has the highest values of the overpressure at distances 4-7 m from the activation spot, as well as the longest durations of the positive phase of the pressure. This composition also has the highest impulse at distances 3-5 m. Composition with Mg has higher impulses at 7-9 m, as well as positive phase duration.

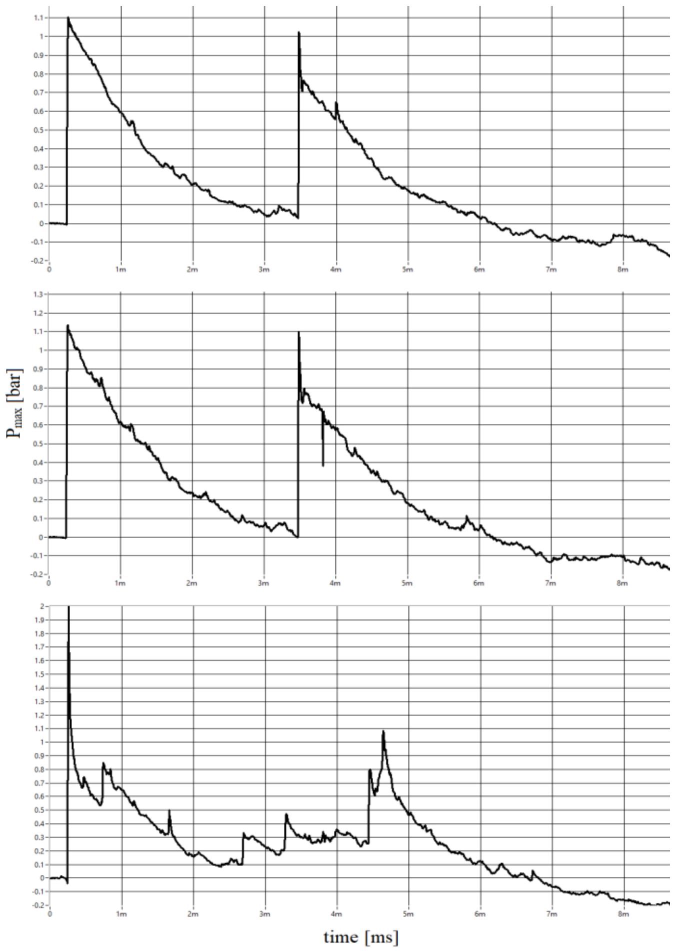

Figure 1. Diagrams Δp = f (t) for charges IPN/Al, IPN/Mg and TBE PBX (top to bottom)

3.2. Infrared imaging results

The obtained recordings from the IR camera were transformed into temperature-time diagrams providing an insight into the average values of the maximum recorded temperatures in the explosion surrounding and given in Figure 2, for the samples: IPN, IPN/Al, IPN/Mg.

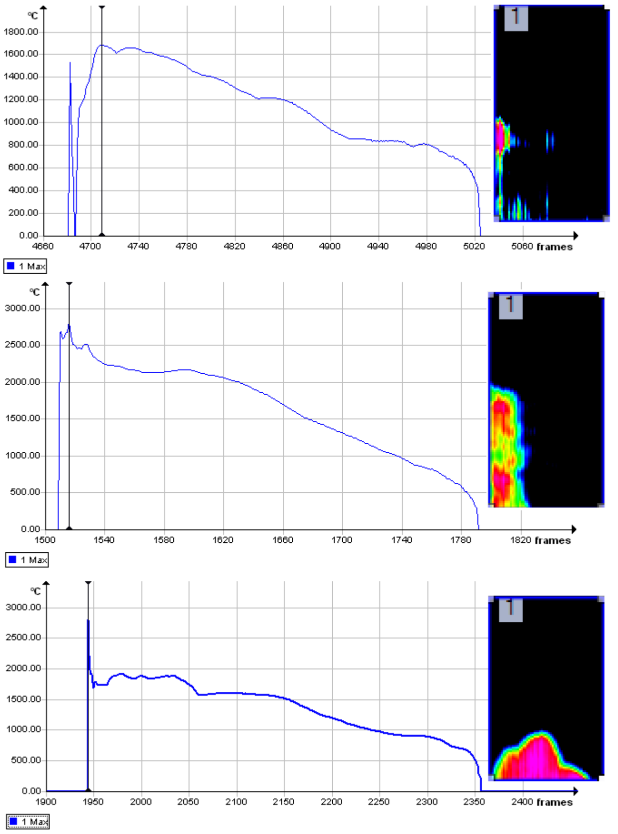

Figure 4. Temperature-time diagrams of the registered maximum temperatures with IR camera

The maximum registered temperatures are given in Table 4. If we observe the curves and compare the time of holding the temperatures above some selected treshold, for example above 500 °C, it can be seen that among the three samples, the one containing Mg had the longest time of post-explosion combustion, or longest duration of the fireball. For the sample TBE PBX the IR recording was unsuccessful, due to operating error. However, earlier IR recordings for this type of TBE compositions have revealed that the registered temperature maximums reach up to 3460 °C, and that the approximate temperatures of post-detonation combustion are in range of 1800-2000 °C [5, 10].

Table 4. Thermal performance of FAE and TBE obtained by IR technique

Composition	Maximum registered temperature, °C	Post-explosion combustion temperature > 500°C duration, s
IPN	1687	2.589
IPN/Al	2822	2.086
IPN/Mg	2794	3.039

It is evident that spherical particles of fuel provide higher registered temperatures of the combustion compared to neat IPN. This is a consequence of different ease of ignition of the applied metal particles in air [8], as aluminium particles combust faster and releasing more heat rapidly, i.e. this composition had higher registered temperatures, while Mg provides longer duration of the fire-ball due to its slower burning.

The size of the thermobaric fireball was approximately the same for both types of the explosives, IPN based and TBE PBX, as can be seen in recordings made using a high speed camera, Figure 5.

Figure 5. Thermobaric fireball: TBE PBX (left) and IPN/Al (right)

Different shape of the fireballs is a consequence of the sample positioning, vertically, i.e. along the wooden stand. However, the widthe and height of the fireballs are similar in both cases.

4. CONCLUSION

Large-scale field tests were performed on thermobaric explosive charges in order to compare gelled IPN-based compositions with TBE PBX. The experimental tests demonstrated that there is a significant difference in the performance of the prepared mixtures with Al and Mg regarding the blast and thermal output. The IPN-based compositions containing Al and Mg have significantly higher blast parameters and thermal output compared to non-metalized IPN, but TBE PBX have the highest blast parameters from 4 to 7 meters from the activation spot.

These measurements provided crucial insights into the spatial distribution and intensity of the blast effects, which are essential for understanding the potential destructive capability of thermobaric explosives.Overall, the comparative study of FAE and TBE formulations not only contributes to advancing scientific knowledge in explosives research but also serves practical purposes in military and industrial applications. By elucidating the blast and thermal characteristics of these powerful explosives, researchers can better optimize their design and deployment strategies for various operational scenarios.

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