Assessing the parameters of blast waves in the air generated by the detonation of 4,4',5,5'-tetranitro-2,2'-biimidazole dihydrate and 3,3'-diaminoazoxyfurazan (DAAF)

Mateusz SZALA, Rafał LEWCZUK, Józef PASZULA – Division of New Technology and Chemistry, Military University of Technology, Warsaw

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Introduction

Until recently "explosives" were associated solely with broadly defined military applications. Because of the more and more common use of chemical compounds and mixtures capable of causing an explosive conversion in such lines as: coal mining and petroleum, automotive industry, metallurgy or construction, the knowledge of the applications of high energy compounds becomes more and more widespread. Recently, the illegal use of explosives in the worldwide known acts of terror has become especially noticeable. Painful is the fact that that the amount of explosives used in a single terrorist attack is relatively low, and the direct range affected by the blast wave and shrapnels is small, but the psychological effect and impact on social consciousness is immense.

The largest consumers of explosives in Poland include: mining (tens of thousands of tons per year [1]) and the army (tens of tons per year [2]). The widespread use of explosives in coal mining keeps its price at a low level. In military applications the price of explosive matters, but it is not of key importance. The priority of national defense is out of the question, therefore the research on new explosives covers a wide range of their functional properties.

Analyzing the specialty literature covering the production and military applications of explosives a few development trends can be observed. The most important of these include: continual improvement of their safety as well as ammunition they are used in, which stimulates the intensive development of explosives and mixtures featuring reduced sensitivity to initiating stimuli including: impact, friction, heating, static electricity, shooting through and cumulative stream. Another development path is the search for explosives featuring highest possible detonation parameters including high detonation velocity and pressure. In this case the sensitivity to initiating stimuli is not of key importance, therefore the strongest currently known explosives are usually used after desensitization with natural and synthetic polymers. The last group consists of enhanced demolition capacity explosives with moderately high detonation parameters, but the duration of overpressure following the explosion is even up to several tens longer than in the case of a classic strong explosive [3].

One of the examples of modern low-sensitivity explosives is 3,3'-diaminoazoxyfurazan (DAAF), whose compound structure is presented in Figure 2. This compound was first described in 1981 by Solodyuk [4] and since then the interest in DAAF has been still at a high level. At a density of 1.75 g·cm^{-3} the velocity and pressure of DAAF detonation are, respectively, 8.0 km/s and 31 GPa. DAAF sensitivity to friction exceeds 360N, but its sensitivity to impact depends, to a considerable extent, on the crystal shape and size. The product obtained after recrystallization in the form N-methyl pyrrolidone (NMP)/ethanol shows a sensitivity to impact of 20J [5]. Low DAAF sensitivity is contributed to the lack of nitro group in the compound and hydrogen bonds created between its molecules. Despite its low sensitivity DAAF features a low critical detonation diameter with a value not lower than 2.0 mm [5].

4,4',5,5'-tetranitro-2,2'-biimidazole (TNBI) is a compound known for 80 years [6], but it is only recently that a more intense interest in studying its properties has been observed. TNBI in its pure form is sensitive to steam found in the air and it dehydrates to form a dihydrate being stable in storage. At a density of 1.72 g·cm^{-3} the detonation velocity of TNBI·2H_2O is 7.9 km/s [7]. TNBI·2H_2O sensitivity to friction exceeds 360 N, while its sensitivity to impact is 40J [8].

From a technological point of view, the level of raw material resources necessary to produce TNBI and DAAF depends on natural raw materials. The two mentioned compounds are obtained from simple chemical compounds being industrial raw materials (glyoxal aldehyde, ammonia, acetic acid and hydroxylamine).

The aim of the presented study was to specify the basic blast wave curves generated in the air by the detonation of DAAF and TNBI·2H_2O. The results obtained for new materials were compared with the same parameters determined for TNT and octogen (HMX).

Experimental part

3,3'-diaminoazoxyfurazan (DAAF) and 4,4',5,5'-tetranitro-2,2'-biimidazole (TNBI) were synthesized in the Department of Explosive Materials, Military University of Technology. Diaminoazoxyfurazan was obtained as a result of the oxidizing coupling of two diaminofurazan (DAF) molecules in sour environment, while diaminofurazan (DAF) was synthesized by the thermal dehydration of diaminglyoxime (DAG) [9]. TNBI was obtained in the direct nitration of 2,2'- biimidazole (BI) using the original method developed by the Department of Explosive Materials at the Military University of Technology [7]. 2,2'- biimidazole (BI) was synthesized by condensing the aqueous solution of ammonium acetate with glyoxylaldehyde [10]. The schemes outlining the process of synthesizing the compounds are presented in Figures 1 and 2. TNBI forms a stable dihydrate (TNBI·2H_2O) and this was the form used in our studies. Remaining compounds used in experiments (TNT, HMX) were obtained from commercial sources.

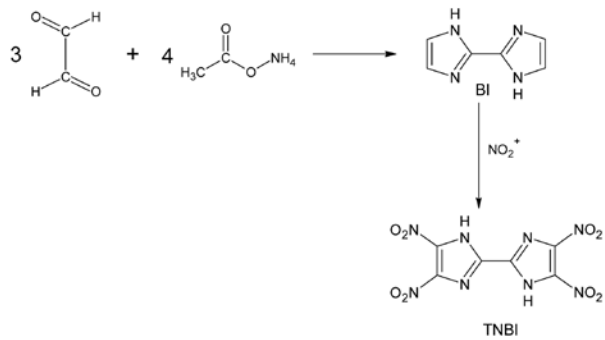

Fig. 1. Synthetic scheme outlining the preparation of TNBI

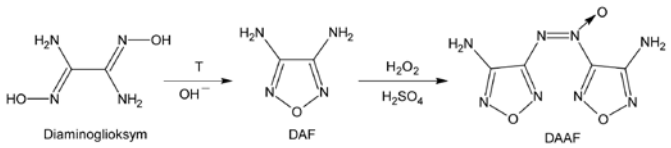

Fig. 2. Synthetic scheme outlining the preparation of DAAF

Analyzing the curves of blast waves

While measuring the pressure of blast waves four piezoelectric sensors series 137A were used. The sensors are dedicated to the measurement of transient blast wave overpressure. The sensors were distributed in pairs at a distance of 1.0 and 1.5 m from the explosive charges under analysis. A voltage signal from the sensors obtained via amplifier was recorded on a digital oscilloscope, while the characteristics in the form of text files were saved on a PC hard drive and processed in an MS Excel spreadsheet.

Charges for measuring the blast wave pressures were made by using the cold-pressing method. The diameter of charges under analysis was 16 mm. The cylindrical pieces of pressed material were connected with an adhesive tape and provided with a detonator made of 6.7 g phlegmatized octogen (HMX). The weight of explosive material under analysis in each trial was 34 g. Figure 3 presents a photo of the three examples prepared to measure the overpressure of blast waves. The charges differ in length because of the difference in density of compounds under analysis, and were, respectively: TNBI·$2H_2O$ 1.72 g·cm^{-3}, DAAF 1.75 g·cm^{-3}, HMX 1.78 g·cm^{-3}, TNT 1.59 g·cm^{-3}.

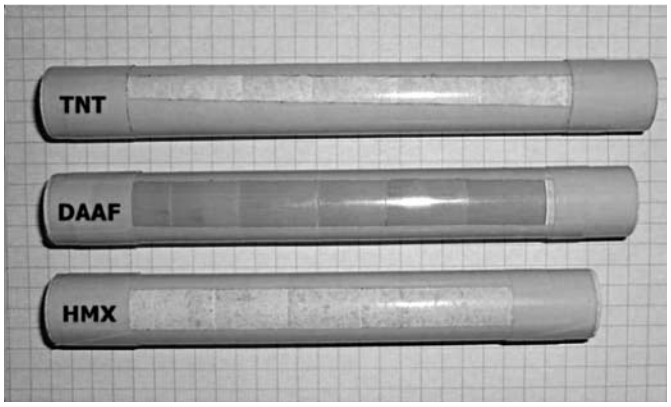

Fig. 3. Charges of TNT, DAAF and HMX before measurements

Figures 4 and 5 present the recorded curves for blast waves obtained for TNBI·$2H_2O$ and DAAF charges.

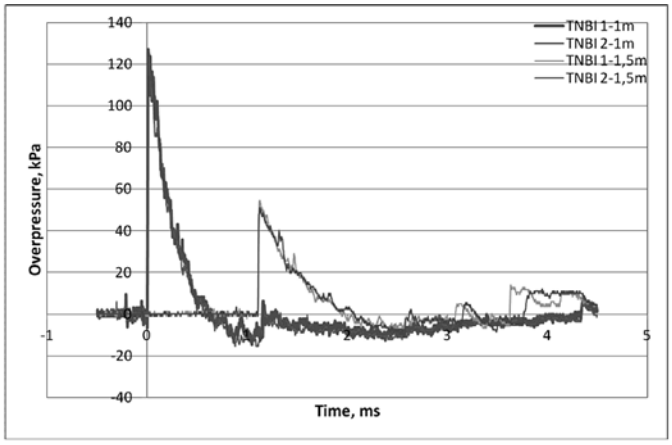

Fig. 4. Overpressure curves for blast waves after the detonation of TNBI·$2H_2O$

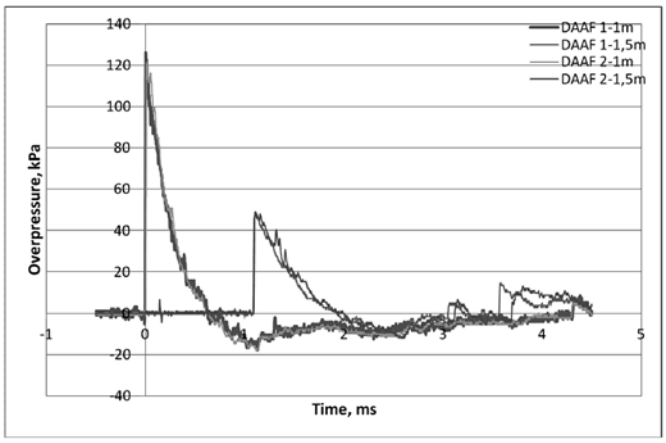

Fig. 5. Overpressure curves for blast waves after the detonation of DAAF

In order to compare the results obtained for explosives under analysis, the levels of blast wave overpressure generated by the explosion of TNT and HMX charges were measured.

The recorded pressure-time results for blast wave overpressure were approximated by using the modified Friedlander equation (eq.2.1).

$$P = P_s e^{-at}\left(1 - \frac{t}{t_+}\right) \qquad 2.1$$

This procedure makes it to possible to minimize the effect of interference recorded while taking the pressure measurement. The results of experimental curve approximations and the basic blast wave curves are presented in Table 1. The parameters determined based on approximated curves include blast wave overpressure (ΔP), overpressure phase duration (t_+) and negative phase impulse (I_+).

Table 1

Blast waves parameters obtained from experimental curves presented in Figures 4 and 5

MW	Distance from the charge					
	1.0 m			1.5 m		
	ΔP, kPa	t_+, ms	I_+, Pa·s	ΔP, kPa	t_+, ms	I_+, Pa·s
TNBI·$2H_2O$	125.02	0.549	25.26	51.38	0.912	17.23
DAAF	121.98	0.584	26.22	50.09	0.904	16.69
TNT	119.07	0.571	24.96	46.85	0.918	15.83
HMX	120.09	0.664	29.38	53.48	0.931	18.35

The results of blast wave curve measurements show that the highest values from among the compounds under analysis are obtained for the TNBI·$2H_2O$ charge. The blast wave parameters for DAAF remain at the level of results obtained for the reference charges of TNT and HMX. It should be noted that as distance increases, the lowest overpressure drop is observed for HMX. It may be the effect of the largest expected amount of gas products generated in this case as compared with remaining charges. The lowest parameter values are obtained for the TNT charge. It features the lowest detonation parameters (detonation velocity, pressure and temperature) and generates the lowest amount of gas products.

Conclusions

Tetranitro biimidazole dihydrate (TNBI) and diamino azoxyfurazane (DAAF) are low-sensitivity explosives featuring blast wave parameters typical for high explosives. The detonation of TNBI·$2H_2O$ within a distance of 1.0 m generates higher overpressure than the one generated by the same size HMX charge, but it should be noted that only one out of three wave blast parameters exceeds the value recorded

for octogen (HMX). The values of positive phase duration and impulse for TNBI·2H_2O are lower than the ones obtained for octogen (HMX). At a distance of 1.5 m the overpressure generated by TNBI·2H_2O is still higher than the one recorded for TNT and DAAF, but it is lower for the value measured for octogen (HMX). In the future tetranitro biimidazole dihydrate (TNBI) can be used as a replacement for the relatively expensive octogen (HMX). However, the use of TNBI·2H_2O requires improving the solutions making it possible to produce it at least at a partially-industrial scale.

Diamino azoxyfurazane (DAAF) shows lower parameters for the generated blast waves than TNBI·2H_2O, but it is worth noticing that at a distance of 1.0 m it features an impulse, whose level is lower only for octogen (HMX). Thanks to good blast wave parameters and reduced sensitivity to mechanical stimuli, in the future DAAF can be used as a replacement for TNT.

Acknowledgments

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Mateusz SZALA – Sc.D., (Eng.), graduated from the Faculty of Chemistry at the Warsaw University of Technology (2004). He received his doctoral degree at the Division of New Technologies and Chemistry, Military University of Technology (2008) where he currently works as an assistant professor. He is co-author of 2 monographs, 34 papers in both domestic and international scientific journals and 24 messages at domestic and international conferences. His research interests include: synthesis of high-nitrogen compounds and the combustion synthesis of carbon and ceramic materials.

e-mail: mszala@wat.edu.pl; phone: +48 22 683 93 82

Rafał LEWCZUK – M.Sc., graduated from the Division of New Technologies and Chemistry, Military University of Technology (2012), where he is currently a doctoral student. He is the author or co-author of 2 papers in both domestic and international scientific journals and 4 speeches given at domestic and international conferences. His research interests include: synthesis of polyheterocyclic compounds (PHCs) and natural organic compounds.

Józef PASZULA – Sc.D., (Eng.), graduated from the Faculty of Weapons and Military Aerospace at the Military University of Technology (1989). He received his doctoral degree at the Faculty of Mechatronics, Military University of Technology (2000). He currently works as an assistant professor at the Division of New Technologies and Chemistry, Military University of Technology. He is the author or co-author of 49 scientific publications and 25 messages at domestic and international conferences. His research interests include: explosion mechanics and studying the detonation-associated chemical processes.