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**N-COMPONENT EXPLOSIVE SYSTEMS:
FEASIBILITY STUDY**

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July 11, 1974

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N-COMPONENT EXPLOSIVE SYSTEMS: FEASIBILITY STUDY

ABSTRACT

A fuel/oxidizer system, TATB (triamino-trinitrobenzene) and HAP(ss) (a saturated solution of hydroxyl ammonium perchlorate), was used to evaluate the characteristics of a multicomponent explosive system for weapons program applications. Both the fuel and oxidizer are individually nonexplosive (or extremely insensitive to impact), and as such their use in nuclear weapons systems would minimize the danger of unintentional detonation as long as the components remain separated. A viable explosive is produced only when the components are combined. Techniques used in preparing the explosive and tests conducted to evaluate explosive performance are discussed. The TATB/HAP(ss) system, although considerably deficient in energy, lends itself to much of the developmental aspects of the study due to the relatively innocuous nature of the individual components. Based on some of the work described in this paper, the concept of using a fuel/oxidizer system appears feasible. Energy output is low, but uniform. Higher-energy systems will need to be developed. There is evidence that such systems can be achieved by using oxidizers with greater oxygen density.

INTRODUCTION

A multicomponent (n-component) explosive system depends on the use of nonexplosive (or extremely insensitive) individual components which provide a viable explosive only when combined. For nuclear weapons applications, an n-component explosive would reduce the probability of an unintentional detonation which could lead to local but uncontrolled dispersal of nuclear components.

The feasibility of using an n-component explosive for weapons program applications is being examined. For this study, a two-component, fuel/oxidizer system was selected for evaluation.

FUEL/OXIDIZER SYSTEM

Fuel

TATB (1,3,5 triamino-2,4,6-trinitrobenzene), an extremely insensitive explosive which is classified as a flammable solid, was selected as the fuel candidate for the fuel/oxidizer system. TATB is dense (1.94 Mg/m^3 crystal density), and its chemical and initiation properties enable it to be handled with relative ease.¹ Because oxygen is

part of its chemical composition, the use of TATB reduces the amount of oxidant which must be supplied. TATB would be used in the form of an immobile, porous bed of solid particles into which a liquid oxidant would be introduced.

Oxidizer

In choosing an oxidant, a tradeoff was necessary between high oxygen content and various unfavorable characteristics. The more potent oxidizers have drawbacks which at this stage of the study eliminated them from consideration. Some of these undesirable features are²:

- Solid phase at room temperature (true for almost all of the metallic and nonmetallic perchlorates).
- Extreme toxicity (e.g., tetranitromethane and halogenated compounds).
- High vapor pressure and instability at room temperature (e.g., some oxides and halogenated compounds).
- Extreme initiation sensitivity (both high and low) and reactivity (e.g., oxides, superoxides, and some of the compounds mentioned above).

Tetranitromethane (TNM) would make a good oxidant because of its high oxygen content. Archibald³ conducted a cylinder test using 50.5 wt% TATB, 38.8 wt% TNM, and 10.7 wt% aluminum powder. The performance of this explosive was impressive, being slightly greater than that of LX-04 (85 wt% HMX, 15 wt% Viton^{*}). TNM, however, is difficult to handle because of its extreme toxicity. It is also detonable, and from an applications standpoint, its freezing point of 287 K may limit its use.

After considering the possibilities, a saturated solution of hydroxyl ammonium perchlorate, HAP(ss) ($\text{NH}_3\text{OHCIO}_4$) was the oxidant chosen for this feasibility study. HAP has none of the listed undesirable features, but only at the expense of oxygen density. A saturated solution, HAP(ss), has a density of 1.8 Mg/m^3 and contains 67 wt% HAP. It is somewhat more viscous than water. The density of available oxygen is 0.72 Mg/m^3 vs 1.2 Mg/m^3 for solid HAP, 1.07 Mg/m^3 for TNM, and 1.46 Mg/m^3 for LiClO_4 .

Preparation of TATB Matrix

For optimum explosive performance, a large void fraction is required in the matrix to permit eventual combination with the liquid oxidant. The density and homogeneity of the matrix must not be affected by a standardized use environment.

*Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Atomic Energy Commission to the exclusion of others that may be suitable.

Isotatic Pressing – Matrix preparation was first attempted by isostatically pressing TATB particles having a nominal size of 60 μm . Consolidated pellets were produced by this method, but the resultant void volumes were too low to accommodate the volume of oxidizer necessary for even minimal performance. The results of these pressings of TATB powder are summarized in Table 1.

Table 1. Characteristics of isostatically pressed TATB powder.

Nominal particle size (μm)	Initial bulk density (Mg/m^3)	Fraction theoretical maximum density after pressing	Void fraction	Integrity
60 (B-144) ^a	0.94	0.80	0.20	} Cohesive cake formed. Easily absorbs liquid (n-heptane) without loss of integrity.
6-7 (NOL) ^a	—	0.70	0.30	
60	0.94	0.70	0.30	} Cohesive cake, but disintegrates in n-heptane.
6-7	—	0.60	0.40	
60	0.94	0.65	0.35	Crumbles when handled.
60	0.94	0.60	0.40	Does not cake.

^aTATB lot identification.

It appears that a cohesive cake of TATB which does not lose integrity when contacted with liquid contains less than 30% porosity. Because a void fraction this low severely limits the amount of liquid oxidizer which can be added, explosive performance could also be severely limited. For example, a fully CO_2 -balanced system of TATB and TNM requires 57 vol% TNM, and a TATB/HAP(ss) system requires 71.5 vol% HAP(ss). These percentages of oxidant are clearly impractical. Although the use of fillers, binders, or some other means of increasing porosity is possible, explosive performance would be severely degraded. However, because acceptable performance has not been defined, an under- CO_2 -balanced system in which a 0.4 to 0.5 void fraction is liquid-filled may be acceptable.

Confined TATB Matrix – To achieve higher porosity, it was apparent that confinement of TATB would be necessary. Under these conditions, a second technique was used for preparing a TATB matrix.

- The TATB particles were first thoroughly wetted with n-heptane, a liquid carrier, in a planetary bladed mixer.
- Mixing continued under continuous evacuation to remove noncondensable gases from both the TATB and the carrier liquid.
- The resultant slurry was vibration-compacted in the desired container.
- Finally, liquid was removed by slow evaporation.

Using this method, homogeneous and highly permeable beds of TATB were produced which had bulk densities of about 1.1 Mg/m^3 and porosities of about 42%. (Some variation in packing is possible through combination of TATB particle sizes.) When confined, the dried, compacted bed of TATB was stable; i.e., neither vibration nor impact caused additional volume reduction.

As a final step, the TATB bed and the transfer tubing were evacuated and the liquid oxidant, HAP(ss), was slowly introduced without additional driving force. The result was a fully saturated system characterized by both homogeneity and stability.

CALCULATED EXPLOSIVE PERFORMANCE

Detonation properties of the fuel/oxidizer systems were calculated using the Kamlet-Jacobs equations⁴ and the TIGER code.⁵

Kamlet-Jacobs Reactions

The detonation pressure and velocity of CHNO-type explosions can be calculated using the empirical equations developed by Kamlet and Jacobs. These equations assume ideal detonation, including chemical equilibrium.

Table 2 compares the calculated explosive performances of two fuel/oxidizer systems in terms of Chapman-Jouquet pressure (P_{CJ}) and detonation velocity (D).

Table 2. Kamlet-Jacobs calculations on TATB/HAP(ss) and TATB/TNM explosive systems.

Explosive constituents	Composition ratio (vol%)	Chapman-Jouquet pressure - P_{CJ} (GPa)	Detonation velocity - D (km/s)
TATB/HAP(ss) (balanced)	29/71	31.0	8.3
TATB/HAP(ss)	55/45	30.4	8.2
TATB/TNM	55/45	32.6	8.6
TATB/TNM (balanced)	43/57	33.4	8.7

First, a stoichiometric, balanced reaction to H_2O and CO_2 products in a 29/71 vol% TATB/HAP(ss) system is compared with that of a 55/45 vol% TATB/HAP(ss) system. The 55/45 vol% TATB/HAP(ss) system is oxygen deficient: the oxygen products formed are H_2O and (primarily CO_2 , with solid carbon being left in excess.

The estimates in Table 2 show a relative insensitivity to TATB/HAP(ss) ratios. Although higher HAP(ss)/TATB ratios improve oxygen-to-fuel balance, the accompanying increase in liquid H_2O could mask any improvement.

Because a TATB/TNM system lacks water, its detonation properties should show a more pronounced dependence on the TATB/TNM ratio. As shown in Table 2, this seems to be predicted by the Kamlet-Jacobs relations. Both P_{CJ} and D are increased for a full, CO_2 -balanced TATB/TNM system.

TIGER Code Calculations

Since the TIGER code allows for a wider elemental product matrix than the Kamlet-Jacobs equations, calculations using it were expected to give a more realistic explosive performance. The same assumptions of ideal (C-J state) detonation and chemical equilibrium are assumed in the TIGER code calculation. In addition, the energy at various expansion ratios in metal acceleration applications is also calculated. Results for n-component systems of current interest are shown in Table 3.

Table 3. TIGER code calculations on TATB/HAP(ss) and TATB/TNM explosive systems with and without Al additives.

Explosive constituents	Composition ratio (wt%)	Theoretical maximum density (Mg/m^3)	Chapman-Jouquet pressure - P_{CJ} (GPa)	Detonation velocity - D (km/s)	Energy relative to HMX ^a	
					Vol. expansion ratio = 2	Vol. expansion ratio = 7
TATB/HAP(ss)	55/45	1.87	32.9	8.57	0.768	0.805
TATB/HAP(ss) (balanced)	30/70	1.84	31.9	8.64	0.714	0.621
TATB/HAP(ss)/Al	47/43/10	1.90	31.3	8.36	0.827	0.853
TATB/TNM	60/40	1.81	31.6	8.14	0.834	0.866
TATB/TNM (balanced)	47/53	1.77	30.7	8.07	0.846	0.899
TATB/TNM/Al	47/43/10	1.85	30.8	8.04	0.839	0.918

^aHMX = 1,3,5,7-tetranitro-1,3,5,7-tetrazacyclooctane ($C_4H_8N_8O_8$).

TIGER calculations show that P_{CJ} and D are relatively insensitive to fuel/oxidant ratios. An oxygen-balanced, 30/70 wt% TATB/HAP system is predicted to have less energy in metal acceleration applications at both low and high expansion ratios than a 55/45 wt% TATB/HAP system. Again, the water which accompanies HAP(ss) produces this effect by lowering the concentration of the active constituents.

P_{CJ} and D in the TATB/TNM systems are also fairly insensitive to fuel/oxidant ratios. However, unlike the balanced TATB/HAP system, energy output does increase at all expansion ratios in the oxygen-balanced system (47/53 wt% TATB/TNM). The addition of aluminum in oxygen-deficient systems should give pronounced improvement in energy output. In fact, oxygen-deficient but aluminized systems are calculated to give higher energy than oxygen-balanced systems lacking aluminum. This may be an important factor in resolving porosity-limited systems.

EXPERIMENTAL MEASUREMENTS OF EXPLOSIVE PERFORMANCE

To obtain qualitative measures of explosive performance, several types of experimental tests were performed using TATB/HAP(ss) mixtures prepared as described in this report.

Plate Dent Tests

Plate dent tests are useful because, within the limits of approximately 10 to 40 GPa, P_{CJ} is proportional to dent depth.⁶ By calibration with known standards, absolute P_{CJ} can be approximated.

Each plate dent test consisted of a 25.4-mm-diam $\times$ 31.8-mm-thick explosive charge, heavily confined, initiated by an unconfined booster system comprised of an SE-1 detonator, a 12.7-mm-diam $\times$ 12.7-mm-thick tetryl pellet, and a 25.4-mm-diam $\times$ 12.7-mm-thick PEX-9404 donor. The large donor was used to assure detonation of about 0.5 theoretical maximum density TATB. In some instances, aluminum powder was added to increase the heat of detonation and to ease initiation for possible enhancement of performance. Detonation velocity was measured with BaTiO₃ pins, and relative performance of the charge was determined by the resultant dent depth on a witness plate made of either mild steel or copper.

The results of tests with steel witness plates are summarized in Table 4. Note that first two tests in Table 4 provided reference points: the ZnCl₂ solution (1.8 Mg/m³) is inert.

The dent tests gave positive initiation and reaction. For comparison, COMP-B, grade A [63/36/11 wt% RDX (C₃H₆N₆O₆)/TNT (C₇H₅N₃O₆)/WAX], which has a P_{CJ} of 29.5 GPa, gives a dent depth of about 7.6 mm (0.300 inch). The influence of aluminum powder (99.5%, 30-mesh; 25 to 50%, 325-mesh) is slightly positive, but the unusually large spread in dent depths obtained in the two TATB/HAP(ss) tests without aluminum

Table 4. Steel plate dent data for TATB/HAP(ss) and TATB/HAP(ss)/Al explosive systems.

Explosive constituents	Composition ratio (vol%)	Dent depth (mm/inch)	Detonation velocity - D (km/s)
TATB/Air	57/43	4.57/0.180	—
TATB/62.5% ZnCl ₂ solution ^a	57/43	5.56/0.219	—
TAB/HAP(ss)	58.4/41.6	6.39/0.252	7.06
TATB/HAP(ss)	57.4/42.6	7.27/0.286	7.20
TATB/HAP(ss)/Al	48.5/48.1/3.4	7.52/0.296	6.65
TATB/HAP(ss)/Al	46.4/47.1/6.5	6.82/0.269	7.08

^aThe 62.5% solution of ZnCl₂ was used in place of HAP(ss).

creates some uncertainty in the interpretation. A considerable amount of fracture and spall in the witness plates was evident in the tests containing HAP(ss). This contributed to uncertainty in the depth measurements and prompted select repeat tests using copper witness plates. Copper, being more ductile, would resist brittle failure and thereby reduce subsequent error in depth measurement and interpretation. The results of these tests are summarized in Table 5.

Table 5. Copper plate dent data for TATB/HAP(ss) and TATB/HAP(ss)/Al explosive systems.

Explosive constituents	Composition ratio (vol%)	Dent depth (mm/inch)	Detonation velocity - D (km/s)
TATB/HAP(ss)	52.9/47.1	12.85/0.5050	—
TATB/HAP(ss)	52.6/47.4	12.70/0.5000	7.36
TATB/HAP(ss)/Al	53.7/43.0/3.3	12.74/0.5016	7.47
TATB/HAP(ss)/Al	47.1/46.3/6.6	12.77/0.5029	7.09

Although dent reproducibility is obvious in the two tests without aluminum, there is an unexpected lack of change in dent depth with the addition of aluminum. The detonation velocity, however, rises with 3.3 vol% Al, but drops with greater aluminum content.

With only a limited number of tests, the effect of aluminum in TATB/HAP(ss) explosive systems is still uncertain. As shown in Table 3, TIGER code calculations predict small changes in P_{CJ} with aluminum additive. The plate dent tests seem to confirm this. However, although the TIGER code predicts higher energy output with aluminum additive, this mode of explosive performance is apparently not detectable in the plate dent tests.

Cylinder Test

A more accurate measure of an explosive's performance is its ability to accelerate metal. A cylinder test⁷ provides this measure.

In a cylinder test, a precision-made copper tube 5.08-cm i.d. × 30-cm long is filled with the explosive to be tested. Using streak camera techniques, the radial motion of the tube wall is measured at about 20 cm from the initiated end. The wall velocity measured at volume expansion ratios of 2 and 7 is indicative of explosive performance normal and tangential to the metal, respectively. Six pairs of shorting pins provide detonation velocity data.

Table 6 shows the specific kinetic energy delivered to a cylinder wall at two volume expansion ratios for two of the explosive systems discussed in this report and two reference explosives. Figure 1 shows the performances of TATB/HAP(ss) and TNT⁸ relative to COMP-B⁸ as a function of volume expansion expressed as cylinder wall displacement. The specific kinetic energy imparted to the cylinder wall by the

Table 6. Copper cylinder test data for TATB/HAP(ss), TATB/TNM/Al, TNT, and COMP-B.

Explosive constituents	Composition ratio (vol%)	Density (Mg/m ³)	Kinetic energy [MJ/kg]		Detonation velocity - D (km/s)
			Vol. expansion ratio = 2	Vol. expansion ratio = 7	
TATB/HAP(ss)	53.4/46.6	1.85	0.796	0.976	7.35
TNT ^a	—	1.63	0.735	0.975	6.93
COMP-B ^a	—	1.72	1.035	1.330	7.99
TATB/TNM/Al ^b	48.7/43.9/7.4	1.87	1.134	1.550	7.36

^aReference 8.

^bReference 3.

TATB/HAP(ss) explosive is very similar to that of TNT. Although TATB/HAP(ss) energy is quite low, its the metal-accelerating characteristics over the measured expansion period resemble those of a single-component explosive and show none of the nonuniform energy release that might be attributed to a multicomponent explosive. There is a slight reduction (~5%) in delivered relative energy as the expansion progresses from 6 to 24 mm. Fast photography revealed the eruption of detonation gases at several points on the cylinder wall. This "jetting" is attributed to inhomogeneities in the explosive, i.e., to small pockets of gas or liquid. These disturbances, however, either did not occur at the active area of the cylinder wall or they did not affect the measurements.

Measured energy output of the TATB/HAP(ss) relative to HMX at volume expansion ratios of 2 and 7 was 0.568 and 0.560, respectively, compared to TIGER code calculations of 0.768 and 0.805 (see Table 3). Actual performance was, therefore, 26 to 30% below calculations. The difference could be due to the effects of a multicomponent system. On the other hand, Archibald's³ cylinder test data for TATB/TNM/Al (see Table 6) gave energy output relative to HMX of 0.81 and 0.89 at volume expansion ratios of 2 and 7, respectively. TIGER code calculations for a very similar composition (last explosive in Table 3) gives 0.839 and 0.918. There is no clear explanation for why the TATB/TNM/Al system will perform close to calculation, but the TATB/HAP(ss) won't.

Miscellaneous Tests

As for all new explosives, a cursory examination of explosive characteristics was performed in a series of miscellaneous tests. These tests included impact sensitivity tests (drop hammer), determination of thermal decomposition products (chemical reactivity test), and observation of thermal stability and behavior (differential thermal analysis). The results of these measurements for various combinations of TATB, HAP(ss), and aluminum are summarized in Table 7.

Fig. 1. Kinetic energy delivered to cylinder wall by 53.4/46.6 vol% TATB/HAP(ss) and TNT relative to COMP-B.

Table 7. Data from miscellaneous tests of various combinations of TATB, HAP, and Al.

Explosive constituents	Composition ratio (wt%)	Drop hammer tests (drop height for 50% initiation frequency, m)	Chemical reactivity tests (gas evolved after 22 h at 393 K)	Differential thermal analysis
TATB (B-144)	—	>1.77	0.060 l/kg total	onset exotherm at 623 K
HAP(ss)	—	>1.77	(expected decomposition products, H ₂ , NO, N ₂ O)	onset decomposition at 448 K — small precursors.
TATB/HAP(ss)	68/32	0.40	40 l/kg total, including 15 l/kg CO ₂ . (0.4 l/kg total, at 353 K)	onset decomposition at 458 K
TATB/Al	~80/20	>1.77	~same as pure TATB	same as TATB
HAP(ss)/Al	40/60	0.35	8 l/kg total	onset decomposition at 458 K
TATB/Al/HAP(ss)	60/9/31	0.18	4 l/kg total	onset decomposition at 458 K
HAP (crystal)	—	0.22	12.4 l/kg total	onset decomposition at ~448 K

CONCLUSIONS

The concept of an n-component explosive system appears feasible from the viewpoint of fabricating a highly porous fuel component into which an oxidant can be injected. Explosive performance depends on the type and percentage of the components used. TATB/HAP(ss), a two-component solid-fuel/liquid-oxidizer system, can be prepared with acceptable homogeneity and stability. Its energy output is considerably below standard, but the energy-release pattern in accelerating metal seems to be reasonably uniform; i.e., it is similar to that of known single-component explosives.

Future exploration of the concept of an n-component explosive system will require developing a more energetic n-component explosive, primarily the oxidizer component; solving problems associated with scaling up to actual geometries; and dealing with problems of long-term homogeneity and stability in environmental conditions imposed by potential applications.

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REFERENCES

1. B. M. Dobratz, Properties of Chemical Explosives and Explosive Simulants, Lawrence Livermore Laboratory, Rept. UCRL-51319 (1972).
2. S. F. Sarnier, Propellant Chemistry (Reinhold Pub. Corp., N. Y., 1966), 217-302.
3. P. B. Archibald, Lawrence Livermore Laboratory, personal communication (1973).
4. M. J. Kamlet, and S. J. Jacobs, J. Chem. Phys. 48 (1), 23 (1968).
5. W. E. Wiebenson, Jr. et al., Tiger Computer Program Documentation, Stanford Research Institution, Rept. prepared under Contract No. DA-04-200-AMC-3226 (x) (1968).
6. L. C. Smith, Explosivstoffe 6, 130 (1967).
7. J. W. Kury, et al., "Metal Acceleration by Chemical Explosives," in Fourth Symposium (International) on Detonation, U. S. Naval Ordnance Laboratory, White Oak, Md., Rept. ACR-126 (1965), pp. 3-13.
8. F. H. Helm, Lawrence Livermore Laboratory, personal communication (1974).

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