



Review

2,4,6-Triamino-1,3,5-trinitrobenzene (TATB) and TATB-based formulations—A review

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ABSTRACT

This paper reviews the research and development work on 2,4,6-triamino-1,3,5-trinitrobenzene (TATB), and TATB-based formulations of other explosives. Syntheses including the production of nano-sized particles, analytical methods, thermophysical properties, performance, formulations, toxicity and safety of TATB are reviewed in this work.

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1. Introduction

There has been a renewed interest in the synthesis and characterization of new energetic materials during the past two to three decades. This is due in part to find materials of better performance, but also to reduce the loss of lives and property due to accidental

explosions that could occur during the different stages of explosive preparation, manufacture, formulations, load assemble and package operations, and use. Information on thermophysical properties of energetic materials is essential for:

1. Military needs to minimize the collateral damage to all sites other than the targeted sites,
2. Determining the fate of these chemicals in the environment,
3. Detecting hidden explosives—extremely accurate data on vapor pressure are required for development of sensors,

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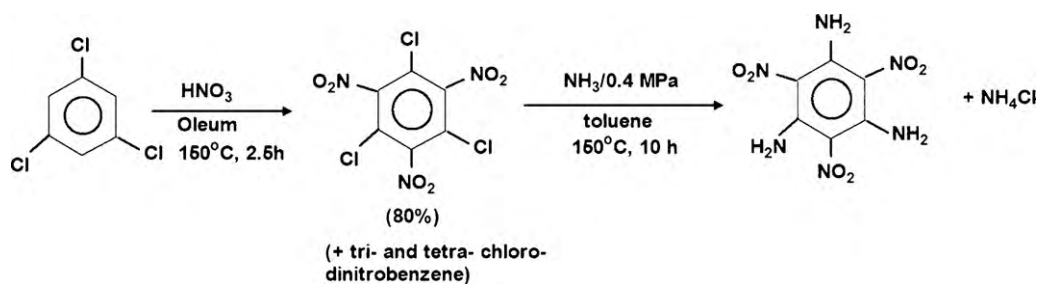


Fig. 1. Synthesis of TATB using 1,3,5-trichlorobenzene. Reproduced from Ref. [5].

4. Proper disposal of these hazardous materials,
5. Preventing smuggling of these materials in their original form or as bombs, etc.,
6. Testing predictive methods associated with the testing and fielding of new energetic materials to minimize the cost and time associated with an experimental program. For example, the prediction of crystal density paves the way in predicting detonation velocities. Enthalpies of formation and sublimation are critical in assessing the potential energy release and performance in a gun or a warhead,
7. Developing models to predict accurately physicochemical properties. In the present collection of properties, it has become evident that models currently used to predict properties are far from satisfactory. Many examples can be cited, and
8. Studying syntheses pathways, reaction mechanisms and products, and exhaust plume signature, etc.

Among the various insensitive high explosives, 2,4,6-triamino-1,3,5-trinitrobenzene, commonly known as TATB, is an attractive insensitive explosive as it satisfies the safety requirements at high temperatures and its resistance to accidental initiation and explosion. In addition, it readily forms eutectics with other explosives such as 1,3,5,7-tetranitro-1,3,5,7-tetrazocane (HMX), trinitrotoluene (TNT), and several others. This paper should be viewed as a companion review to the excellent review by Dobratz [1]. TATB is perhaps the most thermo-resistant insensitive explosive known to date. Although TATB contains an amino group, it is much more stable compared to a nitro compound such as trinitrobenzene.

The potential of TATB as an insensitive explosive was realized during the 1960s. TATB is used in modern nuclear warheads in the military, deep oil well explorations in the civilian community, and as a reagent in the manufacture of liquid crystal displays. It is used extensively in the USA. In recent years it is the preferred conventional secondary high explosive in nuclear weapons [2].

Dobratz [1] cites Jackson and Wing as the earliest workers to mention TATB in 1888, although it was left to Flurscheim and Holmes [3] to synthesize pure TATB by ammoniation of pentanitroaniline. Many processes yield TATB with a small percentage of chlorine but recent attempts to make chlorine-free TATB have been documented. TATB exhibits both monoclinic and triclinic crystal structures and is classified as a heat resistant explosive.

2. Synthesis and manufacturing

The current industrial method is to nitrate 1,3,5-trichlorobenzene to give 2,4,6-trichloro-1,3,5-trinitrobenzene. Nitration is carried out at 423 K using a mixture of nitric and sulfuric acids. It is reacted with ammonia in a toluene medium to yield the product. Other methods of synthesis of TATB have been described in Ref. [1]. The current cost of TATB prohibits its use for civilian applications but new routes for its synthesis could reduce

the cost of production. One such route is patented by Mitchell et al. [4] who used picramide as the starting material. Bellamy et al. [5] have described a new route starting with 1,3,5-trihydroxybenzene for the synthesis of TATB. Although the direct nitration of 1,3,5-trihydroxybenzene can be carried out, Bellamy et al. [5] have suggested a number of modifications. Some of these modifications are shown below.

The authors give details of the above syntheses methods, claim improved yields and report other starting materials. They also show the synthesis of TATB by vicarious nucleophilic substitution [VNS]. Pagoria et al. [6] claim considerable reduction in the cost of production of TATB based on the VNS Process. In this process, TATB is synthesized starting with 4-nitroaniline and converting it to trinitroaniline. Trinitroaniline is then converted to TATB using trimethylhydrazinium iodide in a mixture of dimethylsulfoxide and sodium methoxide. The inventors claim the cost of production to be less than \$90/kg and a reduction of 40% in time.

Thiokol Corporation, Brigham City, Utah, has set up a pilot-plant for the production of TATB as described by Dressen et al. [7]. This process is based on the synthetic route proposed by Bellamy et al. [5]. The overall process yield was 81%. The syntheses routes are shown in Figs. 1 and 2. A similar synthesis method as shown in Fig. 3 was followed by researchers at Pantex, Amarillo, Texas, to reduce chlorine contamination. Aniline was used as a starting material to synthesize 1,3,5-trichlorobenzene by Urbansky and Vasudeva [8] in their attempts to synthesize TATB. TNT was the starting material for Atkins et al. [9] to form 2,3,4,5,6-pentanitroaniline using H_2S and NH_4OH , which was converted to TATB after adding NH_3 , toluene, and CCl_4 . High purity TATB was synthesized by Ott and Benzinger [10] by ammonolysis of 3,5-dichloro-2,4,6-trinitroanisole in toluene at room temperature.

Recently, Yang et al. [11], and Nie et al. [12] have prepared nanoparticles of TATB by amination of TCTNB [2,4,6-trichloro-1,3,5-trinitrobenzene] in toluene medium. The surface area of the particles was $22\text{ m}^2/\text{g}$ and the pore diameter was 1.7 nm. X-Ray Diffraction (XRD) patterns of nano- and micron-sized TATB are shown in Fig. 4. XRD studies showed that particles were about 60 nm in size. The size of these particles may be small for certain formulations, and by changing the experimental parameters it is possible to obtain larger particles. Nevertheless, nanoparticles would give higher surface energy and higher detonation energy.

Pagoria et al. [13] and Agrawal [14] provide excellent reviews of the synthesis of several energetic explosive materials. These two reviews complement one another in discussing the current state of knowledge in the synthesis of explosive and propellant materials. Shorkey et al. [15] synthesized TATB starting with TNT in p-dioxane and reducing with hydrogen sulfide to give 4-amino-2,6-dinitrotoluene. It is then nitrated with a mixture of nitric and sulfuric acids to yield 2,3,4,5,6-pentanitrobenzenamine and reacted with ammonia in methylene chloride to give TATB. Mitchell et al. [16] describe the use of recycled explosives as starting materials for the synthesis of high value products. The authors have

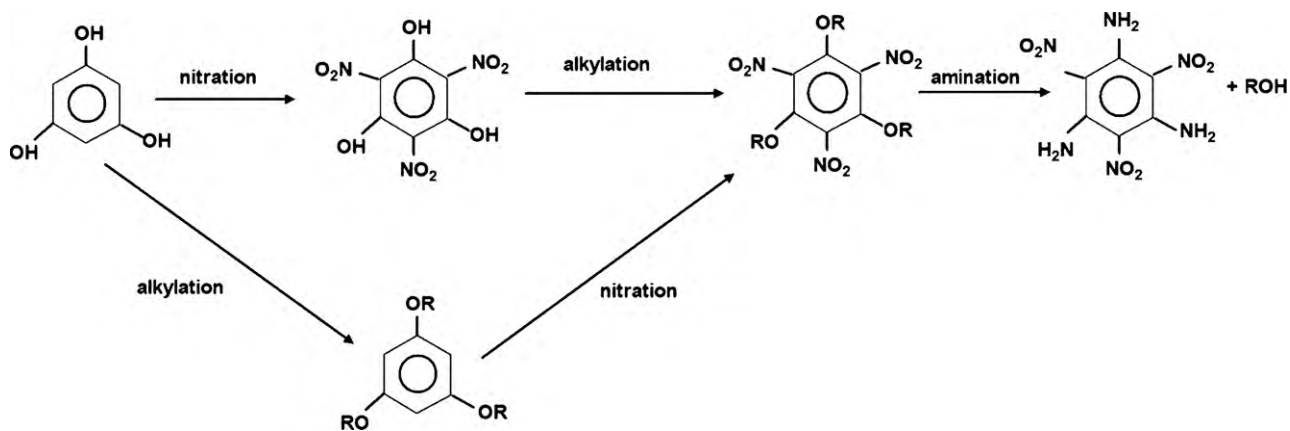


Fig. 2. New synthesis of TATB.
Reproduced from Ref. [5].

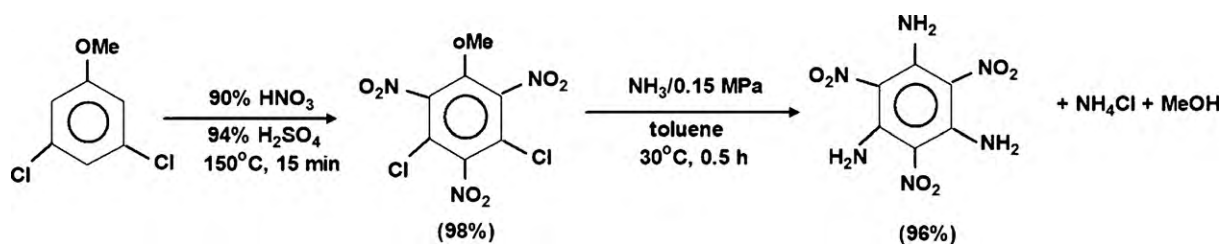


Fig. 3. Modified synthesis of TATB.
Reproduced from Ref. [5].

reviewed the conversion of nitroarenes to TATB, VNS processes for TATB synthesis, and other methods using ammonium picrate and TNT. Szuminsky and Bruno [17] have reviewed the methods of synthesis of TATB, and also discuss the advantages and disadvantages of TNT and TATB as explosives. In a recent paper, Talwar et al. [18] discuss environmentally friendly method of synthesis of TATB and other energetic materials. Starting with the requirements of good green chemistry, the authors discuss the synthesis of high energy density materials, high nitrogen content high energy materials, high performance explosives, and energetic polymers. This study reveals that there is plenty of scope to reduce the cost of production by eco-friendly methods.

3. Structure

TATB has a simple ring structure with long C–C bonds and short C–N bonds with six fractured hydrogen bonds. Agrawal [14] states that there is strong evidence of inter- and intramolecular hydrogen

bonds. These strong hydrogen bonds induce a strong dipole-dipole van der Waals–Keesom force and affect properties such as boiling and melting points, which are evident in TATB. X-ray diffraction studies have indicated two molecules per unit cell and extensive O–N and N–H hydrogen bonding, and a layered structure. This gives rise to polarity and dispersion forces, and affects salivation and physical properties.

TATB is a planar molecule with a triclinic centrosymmetric lattice. Based on the structures shown in Fig. 5, Huang et al. [19] evaluated the vibrational frequencies, and the assignments are shown in Table 1. Except for the weak bands, all other bands have been verified in the experimental spectrum.

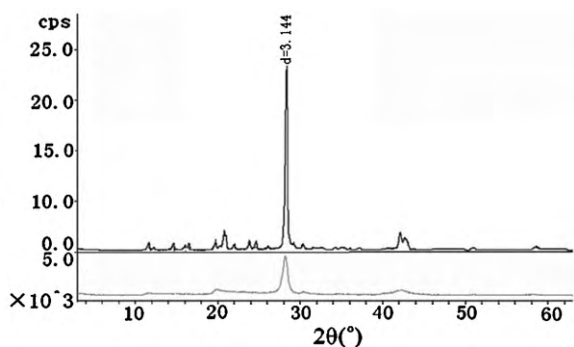


Fig. 4. XRD diagram of nano-TATB (a) and micron TATB (b).
Reproduced from Ref. [11].

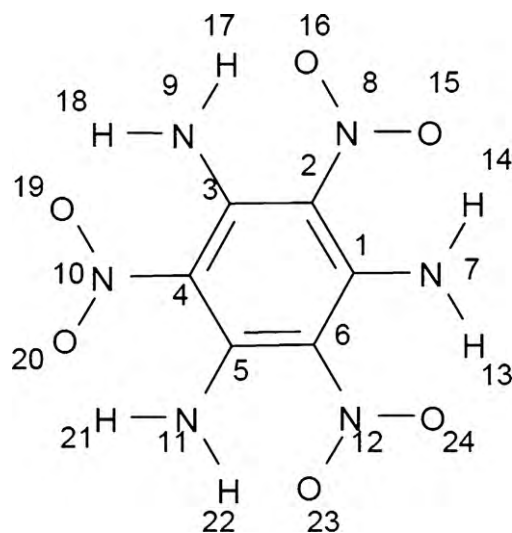


Fig. 5. The equilibrium geometry of TATB.

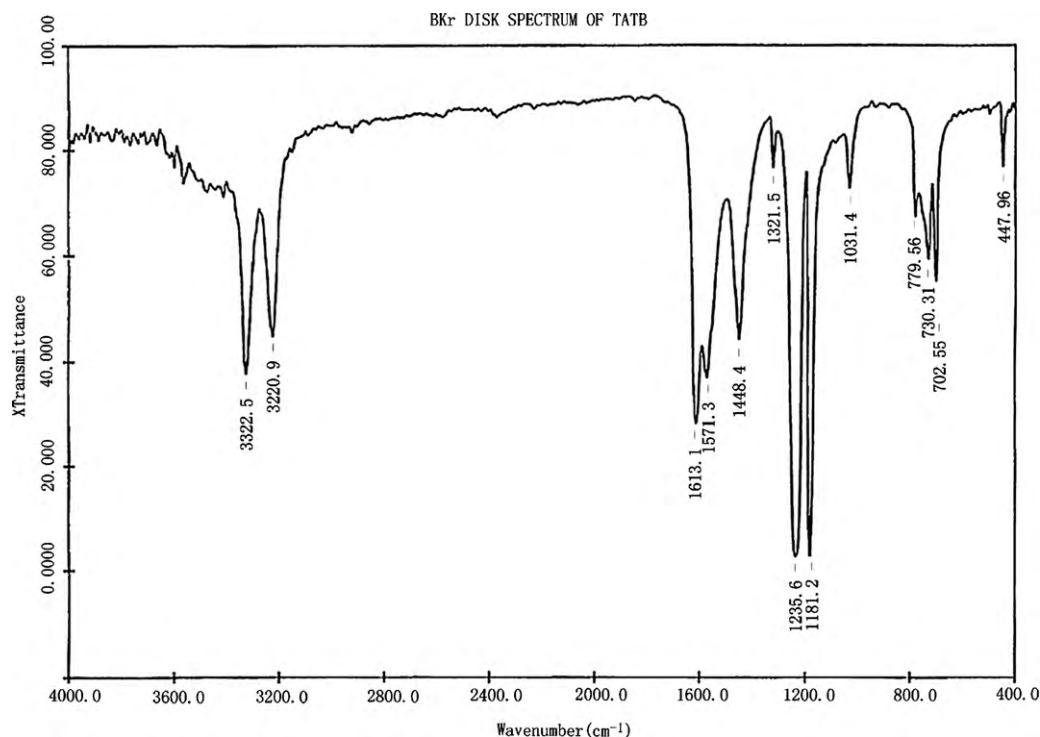


Fig. 6. Experimental IR Spectrum of TATB.

A more detailed assignment of vibrational frequencies has been carried out by Liu et al. [20]. The simulated infrared spectra agree well with the experimental data shown in Fig. 6.

These two studies indicate that there is a conformational change in TATB from crystalline phase to gas phase possibly due to intermolecular hydrogen bonding. The assignments made by Liu et al. [20] agree more closely with experimental data. Kolb and Rizzo [21] used the same structure in their evaluation of thermal expansion of TATB crystal.

TATB undergoes structural changes on heating as observed by Son et al. [22]. This is similar in nature to what one observes with HMX where a phase change occurs from β to δ . Son et al. observed second harmonic generation both in transmission through a thin layer of powdered crystal and in reflection from the surface of a pressed polycrystalline pellet. The results were also confirmed by XRD.

The Differential Scanning Calorimetry (DSC) thermogram [23] in Fig. 7 shows that TATB exothermic decomposing temperature lies between 360 and 390 °C indicating its excellent thermal stability and heat resistance. This shows how some of the properties of nitro explosives can be improved with the introduction of other groups such as amino groups as in the case of TATB. The products of decomposition of TATB appear to be HCN, CO₂, NO₂, and H₂O with an approximate activation energy of 150 kJ/mol [24]. It is likely that C=C homolysis occurs in the form of ring scission leading to these products.

Table 1
Summary of assignment of vibrational modes, cm⁻¹.

Symmetrical N–H stretching	3220.9
Unsymmetrical N–H stretching	3322.5
Unsymmetrical N–O stretching	1571.3
Symmetrical N–O stretching	1235.6
C–N stretching [amino group]	1613.1; 779.56
C–N' stretching [nitro group]	1321.5
Skeletal stretching [ring]	1448.4; 1181.2; 1031.4
Weak bands	932.54; 539.32; 741.48

4. Crystal properties

Crystal density is an important information used to predict the performance of known and unknown energetic materials. The experimental lattice parameters [25] are: a (Å)=9.01; b =9.028; c =6.812; α =108.58°; β =91.82; γ =119.97; space group: P1. The crystal structure of TATB has been calculated based on *Ab Initio* method by Byrd and Rice [26]. Among the different methods used by the authors, it appears that the Perdew-Wang-91 theory gives better estimates of volumes with pressure in comparison with experimental data. A crucial point in such predictions is the inclusion of dispersion forces in the model as they play an important role.

Kolb and Rizzo [21] have carried out X-ray crystallographic studies from 214 to 377 K to monitor the cell constants of triclinic and monoclinic forms of TATB. The calculated cell volumes are shown in Table 2. The authors have carried out linear regression analysis on the data and found the anisotropic volume coefficient of thermal

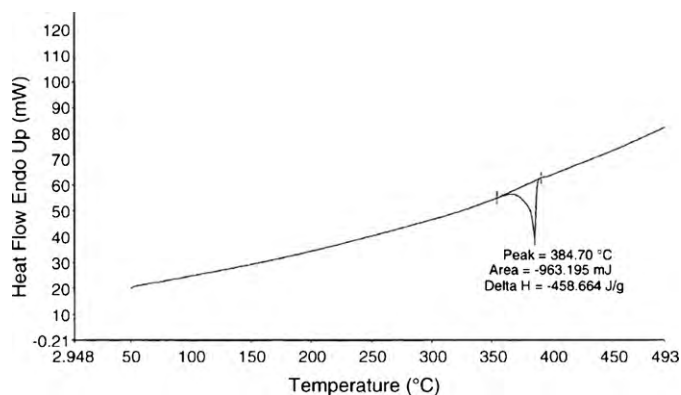


Fig. 7. DSC Profile of TATB
Reproduced from Ref. [23].

Table 2
Experimental cell volume for TATB as a function of temperature.

Triclinic form		C-centered monoclinic form	
Temperature (°C)	Volume (Å ³)	Temperature (°C)	Volume (Å ³)
-59 ± 3	434.5	-57 ± 1	875.2
-45 ± 3	436.2	-47 ± 2	874.1
-36 ± 1	436.3	-34 ± 2	877.3
-26 ± 1	437.4	-23 ± 2	878.5
-13 ± 3	438.7	-12 ± 1	880.2
11 ± 2	441.6	1 ± 1	883.0
23 ± 1	442.9	12 ± 1	885.5
35 ± 1	447.0	23 ± 1	889.8
44 ± 1	446.7	35 ± 1	895.1
54 ± 1	447.7	45 ± 1	896.7
65 ± 1	449.5	57 ± 2	899.1
76 ± 1	451.9	67 ± 1	901.4
83 ± 1	453.4	76 ± 1	903.0
94 ± 1	454.7	86 ± 1	908.3
104 ± 1	456.2	95 ± 1	910.9

expansion to be $30.4 \times 10^{-5} \text{ K}^{-1}$. The unit cell constants are also tabulated in their paper.

5. Effect of particle size

Thermal properties and sensitivity of high explosives depend on the particle size significantly. For TATB, particles with diameter less than 10 μm are considered fine particles. The gap tests suggest that coarse porous high explosives particles are more shock sensitive and finer particles. However, the opposite behavior is found during wedge tests of the same size particles. Price [27] explained that gap tests measure threshold for ignition, and that the reversal occurs because the time to ignition is shorter and the time of buildup of chemical reaction is longer for the coarse than the fine material. Talawar et al. [23] studied various characteristic properties of fine and coarse TATB particles. The average diameter of fine TATB particles was 2 μm and that for coarse particles was 22 μm . Lee [28] also measured some thermal properties of 14 μm TATB particles. A comparison of various characteristics of TATB particles of different size is given in Table 3. Yang et al. [11] prepared nanoparticles of TATB in the size range of 27–41 nm. They noted that the exothermic peak of nano-TATB, due to thermal decomposition, occurs in the region of 356.5–376.5 °C with a maximum at 371.0 °C. There is a shift of approximately 10 °C toward lower temperature compared with micro-TATB.

6. Physical properties

Table 4 provides a list of the general physical properties of TATB that are collected from various literature sources [29–36]. This list

Table 3
Effect of particle size on TATB properties.

Property	Data source		
	Ref. [23]	Ref. [23]	Ref. [28]
Average particle size (μm)	2	22	14
Impact sensitivity ($h_{50\%}$, cm)	124	170	>320 ^a
Friction insensitiveness (kg)	36	36	–
DTA exotherm (onset, 0 °C)	250	255	>350
Peaks in FTIR (cm^{-1})	3220, 1610, 1568, 1226	3313–3324, 1608–1614, 1568–1574, 1222–1224	
DSC			
Peak temperature (T_{max} , °C)	385	384.70	
ΔH (J/g)	–457.71	–458.66	

^a Type 12, cm.

Table 4
Physical properties of TATB.

Properties	Values	Reference
CAS Number	3058-38-6	
Empirical formula	$\text{C}_6\text{H}_6\text{N}_6\text{O}_6$	
Molecular mass (Da)	258.1	
Enthalpy of formation (kJ/kg)	–541.4	[29]
Enthalpy of explosion [H_2O , l] (kJ/kg)	3062	[29]
Enthalpy of sublimation (kJ/mol)	180.3 ^a , 168.2 ^b , 168.1 ^c	a: [30], b: [31], c: [32]
Crystal density (g/cm^3)	1.93	[29]
Melting point (K)	Melts above 573 K but decomposes above	a: [29], b: [33]
Decomposition temperature (K)	594–599 ^a , 623.15 ^b	a: [33], b: [34]
Enthalpy of fusion (kJ/mol)	43.0	[33]
Critical temperature (K)	913	[33]
Critical pressure (bar)	56.5	[33]
Acentric factor	1.802	[33]
Aqueous solubility @ 25 °C	0.16; 0.197; 2.5 [*]	[33]
$\log K_{\text{ow}}$	–1.5; –0.44; 4.74 [*]	[33]
Volume coefficient of thermal expansion [crystal]	$30.4 \times 10^{-5} \text{ K}^{-1}$ [temperature range of 214–377 K]	[21]
Crystal heat capacity at 293 K (J/gC)	1.38 ^a ; 1.09 ^b	a: [35], b: [36]
Thermal Conductivity (J/cmC)	8.0×10^{-3}	[36]

^{*} Ref. [33] reported three different values from three different literature sources.

reveals the disagreement in the values of some of the properties and the need for more accurate values.

It should be noted that there is a fair amount of variation in the literature values of some of the physical properties mentioned in Table 4. A good example is the melting point as Zeman [37], in his differential calorimetric studies on TATB and other compounds, found that TATB starts to decompose at different temperatures depending on the heating cycle. He also quotes a melting point of 603 K based on the work of Bell et al. [38].

7. Thermodynamic properties

Rosen and Dickinson [31] measured vapor pressures and enthalpies of sublimation of high melting explosives including TATB. These authors have made careful measurements of temperatures and pressures but did not mention the purity of TATB used. The impurities in TATB include amino- and chloro-compounds of dinitrobenzene. The vapor pressure of TATB reported in the literature [31,34,39] is summarized in Table 5.

The least squares fit of the vapor pressure to the Antoine type equation is given by:

$$\log_{10} P = 14.6777 - \left[\frac{60261.2}{6.87372 \times T} \right] \quad (1)$$

where T is in K and is different from the fit given by Rosen and Dickenson [31]. When correlating the vapor pressure data into Eq. (1), the values from Ref. [31] were omitted. Vapor pressure data

Table 5
Vapor pressure of TATB.

Temperature (°C)	P ($\times 10^7$ Torr)	Reference
129.3	0.740	[31]
136.2	1.88	[31]
150.0	9.82	[31]
161.4	32.25	[31]
166.4	45.8	[31]
177.3	167.0	[31]
177.3	167.0	[34]
175.0	240.0	[39]
200.0	2100.0	[39]

Table 6
Calculated C_p° (cal mol⁻¹ K⁻¹) in the temperature range of 300–5000 K.

Temperature (K)	Heat capacity (cal mol ⁻¹ K ⁻¹)	Temperature (K)	Heat capacity (cal mol ⁻¹ K ⁻¹)
300	60.3	2000	130.5
400	74.8	2500	133.3
500	86.1	3000	134.9
600	94.9	3500	136.0
800	106.9	4000	136.7
1000	114.7	4500	137.1
1500	125.4	5000	137.5

Table 7
Calculated S° (cal mol⁻¹ K⁻¹) in the temperature range of 300–1500 K.

Temperature (K)	Entropy (cal mol ⁻¹ K ⁻¹)	Temperature (K)	Entropy (cal mol ⁻¹ K ⁻¹)
300	129.8	2000	323.3
400	149.2	2500	352.8
500	167.2	3000	377.2
600	183.7	3500	398.1
800	212.8	4000	416.3
1000	237.6	4500	432.5
1500	186.4	5000	446.9

are very important in predicting the properties of any substance and also in its detection. This table shows the need to generate accurate vapor pressure data. As reported by Agrawal [14,40], the boiling point of TATB is not well defined, and it is insoluble in most of the solvents except sulfuric acid. It starts decomposing close to the melting point.

Osmont et al. [41] have carried out theoretical evaluation of standard state enthalpy of formation at 298.15 K, and heat capacities and entropy in the temperature range of 300–5000 K for various energetic compounds. Their value of enthalpy of formation is 0.7 kcal/mol. Ideal gas heat capacity data are shown in Table 6, and entropy values in Table 7.

8. Solubility

Talawar et al. [23] estimated the solubility of TATB in different solvents at room temperature. Their estimated values are given in Table 8. However, the authors do not mention the method of calculation. They also document the DSC and Thermogravimetric Analysis (TGA) profiles, and mechanical properties of TATB/Polymer-Bonded Explosive (PBX) formulations.

Table 8
Solubility of TATB in various solvents at 298.15 K.

Solvent	Solubility (ppm)
Methanesulfonic acid	820
Hexamethylphosphorotriamide	150
Ethanesulfonic acid	120
DMSO	70
Hexafluoroacetone sesquihydrate	68
N-Methyl-2-pyrrolidone	58
N,N-Dimethylacetamide	33
DMF	27
Tetramethylurea	26
Dimethyl methylphosphonate	22
N,N-Dimethyl propionamide	16
Conc. Nitric acid	14
3-Methylsulfone	13
Pyridine	12
Trimethylphosphate	11
Acetone	3
Acetonitrile, acetic anhydride	1
Trifluoroacetic acid, acetic acid	1

Table 9
Solubility of TATB in sulfuric acid:water mixtures.

H ₂ SO ₄ :H ₂ O	Acid (vol%)	Max amount dissolved (g TATB/100 ml)
1:1	50	>0.02
2:1	66.7	<0.02
4:1	80	-0.24
5.67:1	85	-0.32
7:1	87.5	>1.28
9:1	90	-3.84
Concentrated	100	>24.0

Table 10
Detonation characteristics [48].

Density (g/cm ³)	Detonation velocity (m/s)	Detonation pressure (kbar)	Detonation energy (cal/g)
1.80	7658	259.4	829
1.50	6555	174.6	808

Selig [42] has discussed methods of measuring solubility of extremely low soluble materials and measured the solubility of TATB in various solvents. In the same report, Selig indicated peculiar solubility of TATB in sulfuric acid–water mixtures, which are reproduced in Table 9.

During their study on recrystallization, Foltz et al. [43,44] measured the solubility of TATB in dimethyl sulfoxide (DMSO). The measurements were carried out gravimetrically. The values at 294.35 and 418.65 K were 0.47 and 6.80 g/L, respectively. The authors also discuss larger particles from approximately 60–220 μm for use in different formulations. The enthalpy of detonation of TATB is calculated to be 3.267 against an experimental value of 3.062 kJ/g. [45]. The experimental value has been taken from Ref. [24].

9. Performance

Kennedy et al. [46] describe methods of preparing TATB in the range of 1.2–6 μm and dent profiles in detonation-spreading spot-size tests. The density of the different particles tested varied from 1.693 to 1.810 g/cm³. The results indicate that particle morphology and crystal structure influence the sensitivity of TATB. Similar tests have also been conducted by Tran et al. [47]. Some detonation characteristics of TATB, based on watershock measurements, are listed in Table 10 [48].

Mader [49] used the Becker–Kistiakowsky–Wilson (BKW) equation of state to calculate the detonation velocity of TATB as a function of density. His calculations using 1,3,5-trinitroperhydro-1,3,5-triazine (RDX) parameters and assuming carbon as either graphite or diamond do not show good agreement with experimental data.

Based on the Chapman–Jouguet theory, Borg et al. [50] wrote a code – SDA.FOR – to perform chemical equilibrium calculations for detonation of explosives, and compared their results with the values obtained by Mader [49] for TATB. Table 11 shows the comparison. They also show some results for other explosives and other models.

Becuwe and Delclos [51] compare the sensitivities of 5-nitro-2,4-dihydro-3H-1,2,4-triazol-3-one (NTO), TATB, RDX, HMX and

Table 11
Comparison of SDA.FOR algorithm with Mader [49].

Compound	Density	P_{CJ} (Mbar)		T_{CJ} (K)		D_{CJ} (m/s)	
		BKW	SDA	BKW	SDA	BKW	SDA
TATB	1.895	0.326	0.325	1887	1890	8411	8365

Table 12
TATB/HMX based PBXs and their properties.

Composition	TATB (mass%)	HMX (mass%)	Kel-F 800 (mass%)	Density (g/cm ³)	Velocity of detonation (m/s)	Impact sensitivity (cm)
PBX-9502	95	0	5	1.895	7706	–
X-0344	71.25	23.75	5	1.894	8046	–
PBX-9501	0	95	5	1.832	8802	–
–	0	90	10	1.869	–	<30
–	20	70	10	1.873	–	~60
–	40	50	10	1.878	–	>1920

pentaerythritol tetranitrate (PETN), and show that TATB undergoes spontaneous ignition at a higher temperature compared to other explosives. According to Chevalier et al. [52] the velocity of detonation is higher for HMX compared to TATB but the axial curvature is higher for TATB for any given diameter. They have measured the velocity of detonation for different compositions of TATB.

10. TATB formulations

TATB is combined with other explosives and polymers to produce formulations with varying properties such as densities, velocities of detonation, and impact sensitivity. These formulations make the explosive less sensitive to shock and at the same time impart desirable properties. Hallam [53], and Kolb and Pruneda [54] have discussed the bonding of TATB with Kel-F 800 and studied the effect of solvents, and found that different polymers did not change the characteristics of the TATB surface energies. Agrawal [14] has discussed the combination of TATB with Kel-F 800 using various solvents in order to increase the binding of TATB with the polymer. Pruneda et al. [55] have also discussed the combination of TATB with Kel-F with various solvents to strengthen the binding of TATB with the polymer. The performance of TATB + HMX bonded with Kel-F 800 polymer is shown in Table 12.

Shorky et al. [15] found that 90:10 [mass percent] TATB-Kel-F 800 to be the best combination compared to other compositions and other binders. Stallings et al. [56] carried out experiments with TATB, HMX, and Kel-F to find out the effect of particle size of each one of the explosives with 5% Kel-F 800. They conducted the experiments based on a factorial design and found that particle size had very little effect on corner-turning performance. The experiments were carried out at two different temperatures of 298 and 323 K. Traver [57] used LX-17 with ultrafine TATB to conduct corner-turning and shock desensitization experiments. The detonation waves were measured using a photonic Doppler velocimeter. The model prediction and experimental data are in good agreement. In a recent paper, Willey et al. [58] used ultra-small-angle X-ray scattering technique to study the effect of temperature cycling on different formulations of ultrafine TATB with different binders including Kel-F-800. These studies were carried out in a temperature range of 218–343 K. The experimental results combined with mesoscale models revealed that high glass transition temperature as well as TATB binder adhesion and wetting are important to minimize ratchet growth. These investigators have carried out an earlier study the pore size distribution on thermal cycling of TATB formulations [59].

11. Conclusions

This paper together with the papers referenced herein provides a review of the properties of TATB and its formulations. The values of the properties listed in this paper reveal that there are discrepancies in the reported values, and the prediction models are far from satisfactory. There is a need to collect accurate experimental data and develop better models. This would be useful not only in the case of TATB, but for all insensitive explosives.

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